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LUBRICATION OF POWERPLANT EQUIPMENT

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Revised November, 1990
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LUBRICATION OF POWERPLANT EQUIPMENT

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1. INTRODUCTION

The proper selection and use of lubricants, as well as the care and operation of lubricating equipment is an essential part of any powerplant maintenance program. The purpose of

this bulletin is to provide field personnel with a basic understanding of lubricants and their use, and to act as a guide in the care and operation of lubricating systems.

2. FUNDAMENTALS OF LUBRICATION

The basic purpose of a lubricant is to reduce friction and wear between two surfaces moving relative to one another. In most cases a lubricant also dissipates heat, prevents rust or corrosion, acts as a seal to outside contaminants, and flushes contaminants away from bearing surfaces. In order for the lubricant to accomplish these functions, a lubricant film must be maintained between the moving surfaces. This condition is known as fluid film lubrication.

2.1 Fluid Film Lubrication

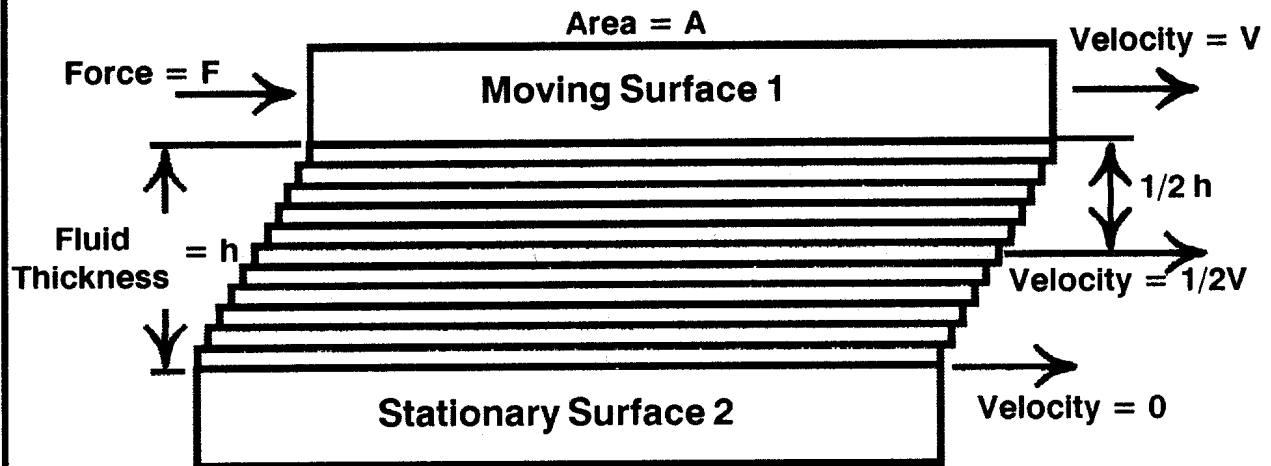
Fluid film lubrication reduces friction between moving surfaces by substituting fluid friction for mechanical friction. Fluid film lubrication is illustrated in [Figure 1](#). Surface 1 moves over Surface 2, separated by a film of fluid. The oil film can be looked at as being made up of many layers. The layer in contact with the moving Surface 1, clings to that surface and moves at the same velocity. Similarly, the layer in contact with Surface 2 is stationary. The layers in between move at velocities directly proportional to their distance from the moving surface. For example, at a distance of $1/2 h$ from Surface 1, the velocity would be $1/2 V$. The force F , required to move Surface 1 across Surface 2 is simply the force required to overcome the friction between the layers of fluid. This internal friction, or resistance to flow, is defined as the viscosity of the fluid. Viscosity will be discussed in more detail later.

The guide bearings of a vertical hydroelectric generator, if properly aligned, have little or no loading and will tend to operate in the center of the bearing because of the viscosity of the oil. In highly loaded bearings, like thrust bearings and horizontal journal bearings, the fluid's viscosity alone is not sufficient to maintain a film between the moving surfaces. In these bearings higher

fluid pressures are required to support the load. If this pressure is supplied by an outside source, it is called hydrostatic lubrication. If the pressure is generated internally, that is within the bearing by dynamic action, it is referred to as hydrodynamic lubrication. In hydrodynamic lubrication, a fluid wedge is formed by the relative surface motion of the journals or the thrust runners over their respective bearing surfaces. The formation of this wedge is similar to the wedge that forms under a speeding boat, pushing the bow out of the water, or under water skis, allowing the skier to skim across the water. [Figure 2](#) illustrates the wedge action in a pivoting shoe thrust bearing. As the thrust runner moves over the thrust shoe, fluid adhering to the runner is drawn in between the runner and the shoe, causing the shoe to pivot, and forming a wedge of oil. As the speed of the runner increases, the pressure of this wedge increases and the runner will be lifted vertically, and full fluid film lubrication takes place.

[Figure 3](#) demonstrates the wedge that forms in a horizontal journal bearing. In Drawing "A", the journal is at rest and the weight of the journal has squeezed out the oil film at "E" so that the journal rests on the bearing surface. As rotation starts, as shown in Drawing "B", the journal has a tendency to roll up the side of the bearing. At the same time fluid adhering to the journal is drawn into the contact area at "F." As the speed increases the oil wedge is formed at "G." The pressure of the oil wedge increases until the journal is lifted off the bearing at "H" as shown in Drawing "C". Drawing "D" shows the condition at full speed. The journal is not only lifted vertically, but is also pushed to the left by the pressure of the oil wedge so that the resultant force from the fluid pressure acts along the line "PO." The minimum fluid film thickness at full speed will occur at "J" and not at the bottom of the bearing.

Fluid Film Lubrication



$$\text{Shear Stress} = F/A = \text{dynes/cm}^2$$

$$\text{Shear Rate} = V/h = (\text{cm/sec})/\text{cm} = 1/\text{sec}$$

$$\text{Dynamic Viscosity} = \text{Shear Stress}/\text{Shear Rate} = (\text{dynes/cm}^2)/ (1/\text{sec}) = 1 \text{ Poise}$$

Figure 1

Pivoting Shoe Thrust Bearing

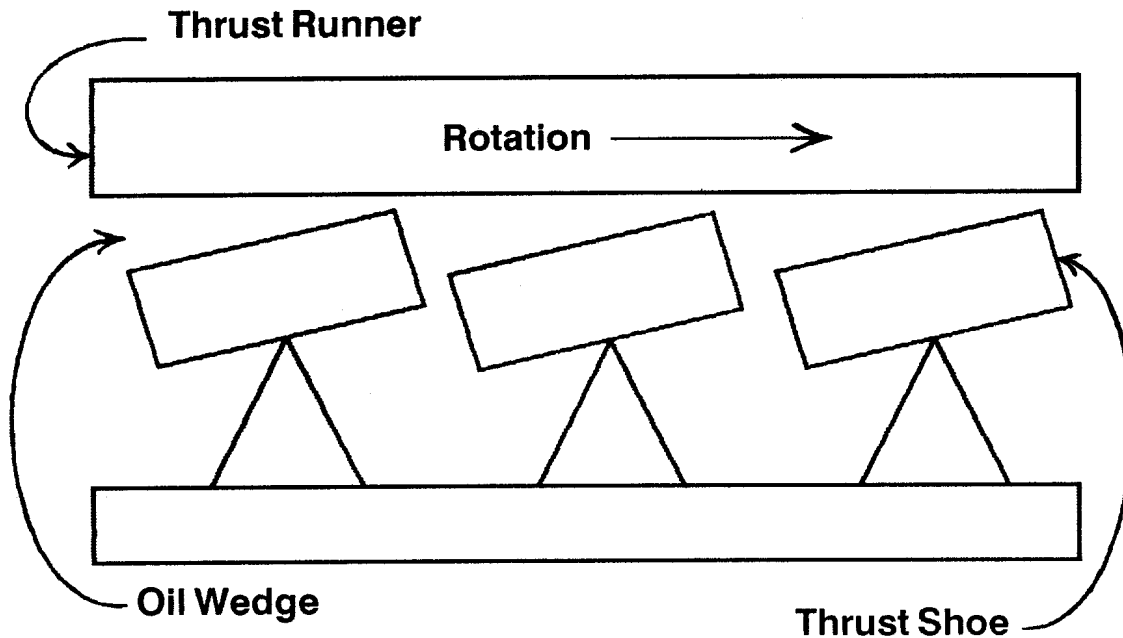


Figure 2

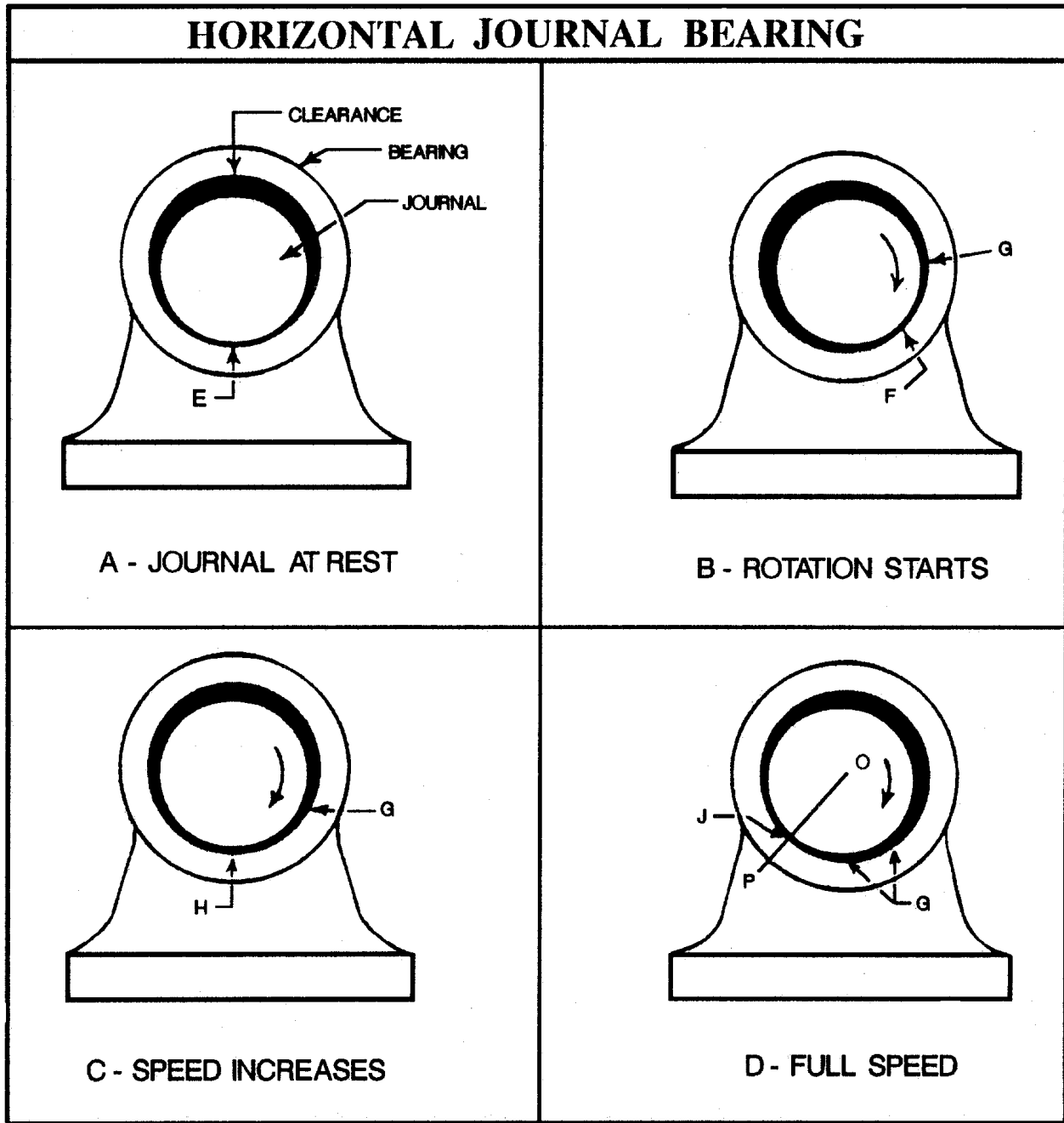


Figure 3

(Courtesy of Conoco Inc.)

In both the pivoting shoe thrust bearing and the horizontal journal bearing, the minimum thickness of the fluid film increases with an increase in fluid viscosity and surface speed and decreases with an increase in load.

2.2 Elastohydrodynamic Lubrication

In instances of very high unit loads and high speeds, as is experienced in antifriction (ball and roller) bearings, cams, and some gears, it is difficult to establish or maintain an oil film with adequate thickness for normal hydrodynamic lubrication. In these special cases, the lubricant is compressed and extremely high pressures are developed. The high pressures increase the lubricant's viscosity and elastically deform the metal surfaces. This allows the load to be spread over a larger area and increases the load carrying capacity. This is referred to as elastohydrodynamic lubrication. In this realm of lubrication an increase in load deforms the metal surfaces rather than affecting the oil film thickness, as the oil film is actually more rigid than the metal.

2.3 Boundary Lubrication

A well designed fluid film bearing will operate with a full fluid film under most circumstances, but under less than ideal conditions, such as during start up and shut down, the fluid film may become so thin that contact may be made between the rubbing surfaces. This condition is called boundary lubrication.

Under boundary lubrication conditions, the lubricant's viscosity alone cannot provide sufficient lubrication. To compensate for this, lubricant additives may be required, or, in the case of hydroelectric generator thrust bearings, an outside pressure source or hydrostatic system may be used.

Some reciprocating equipment, such as pistons in compressors or engines, and slow moving equipment, such as turbine wicket gates, rely on boundary lubrication entirely. Gear teeth also depend on boundary lubrication to a great extent. In order for boundary lubrication to be effective, that is to reduce friction and provide damage control to the rubbing surfaces, a very thin film of lubricant and/or additive must be maintained. This is accomplished through the use of various extreme pressure additives, oiliness additives, friction modifiers, and solid lubricants, such as graphite or molybdenum disulfide.

3. LUBRICANT ADDITIVES

Practically all lubricants contain additives to enhance existing properties, or to impart new properties. Three general classifications of lubricant additives are surface protective, performance enhancing, and lubricant protective.

3.1 Surface Protective Additives

Oiliness Additives. Oiliness, with respect to lubricating oil, is defined as the ability of an oil to reduce friction between moving surfaces. Oiliness additives, usually vegetable or animal fats, enhance oiliness by tenaciously adhering to the metal's surface forming an absorbed film of high lubricating value.

Antiwear Additives. Antiwear additives work by coating the metals surface. If light metal to metal contact is made, the heat from the friction melts the additives, forming a liquid layer between the surfaces. This molten additive layer, being softer than the metal, acts as a lubricant preventing wear of the metal surfaces.

Extreme Pressure Additives. Extreme Pressure (EP) additives work by reacting with the metal to form a compound which acts a protective layer on the metal's surface. As this layer is softer than the metal itself, under extreme pressure conditions, the compound layer wears away first, protecting the metal. As this layer is removed, the EP additive acts to form another layer. In contrast to the action of antiwear additives, EP additives control wear instead of preventing it. Some EP additives, because of their reactive nature, can be corrosive to brass or copper containing alloys. To prevent excessive corrosion, most EP additives are activated by the excessive heat created during extreme pressure conditions but do not react at room temperature.

Tackiness Agent. Tackiness agents act to increase the adhesiveness of an oil or grease.

Corrosion and Rust Inhibitors. Rust Inhibitors protect ferrous (iron or steel) parts by forming a film on the part that resists attack by water. Corrosion inhibitors act in a similar way to protect nonferrous parts and also act to neutralize acids with a basic compound such as calcium carbonate.

Detergents and Dispersants. Detergents and dispersants are used primarily in engine oils to keep surfaces free of deposits and keep contaminants dispersed in the lubricant.

3.2 Performance Enhancing Additives

Viscosity Index Improvers. Viscosity index improvers lower the rate of change of viscosity with temperature. Multi-grade motor oils are the result of the use of viscosity Index improvers.

Pour Point Depressant. Pour point depressants enable lubricants to flow at low temperature.

Demulsifier. A demulsifier promotes the separation of oil and water in lubricants exposed to water.

Emulsifier. An emulsifier promotes the rapid mixing of oil and water to form a stable emulsion. Emulsifiers are sometimes used in motor oils to allow water, formed by combustion of fuel, to be kept in emulsion until engine heat can evaporate it. Emulsifiers are also used in soluble oils used in some metal working operations and in some fire resistant hydraulic fluids. Emulsification is not a desirable property in most hydraulic fluids or turbine oils.

3.3 Lubricant Protective Additives

Oxidation Inhibitors. Oxidation inhibitors, or antioxidants, lengthen a lubricant's service or storage life by increasing its oxidation resistance by binding the free oxygen in the oil or by neutralizing the catalytic effect of metals.

Foam Inhibitors. Foam inhibitors prevent lubricant foaming by decreasing the surface tension of air bubbles, allowing them to combine into large ones which break more rapidly.

3.4 Additive Depletion

Some additives such as, antiwear and extreme pressure additives, and rust, oxidation, and corrosion inhibitors, are consumed as they are used. When all of a particular additive has been consumed, the lubricant is no longer capable of performing as originally intended. Usually this condition requires replacement of the lubricant, but in some cases replenishment of the additive is possible. The lubricant manufacturer should be consulted before this is attempted.

3.5 After Market Additives

There are a number of after market lubricant additives that are being marketed as solutions to many lubricating problems. These additives

may contain teflon or some other "secret ingredient" that supposedly imparts improved lubricating qualities to the lubricant. There may be cases where these additives improve performance in some way, or at least appear to improve performance, but in most cases their usefulness is questionable at best. These additives may actually reduce a lubricant's effectiveness by reacting with some of the additives already in the oil.

The major lubricant manufacturers spend a great deal of time and money formulating their products so that they provide optimum performance for particular applications. If some additive is available that will improve a lubricant to the extent claimed by many of the after market additive distributors, the lubricant manufacturer would have added it to their product.

If a lubricant is not performing as it should, a different lubricant may be required, or some mechanical problem may exist. Before adding anything to a lubricant, the lubricant's manufacturer should be consulted. The lubricant manufacturer can provide information on the possible benefits, or consequences, of the additive, and recommend whether a different lubricant is required.

4. OIL LUBRICATION

A lubricating oil is composed of a base stock blended with various performance enhancing additives. The base stock may be a petroleum oil, a synthetic oil, or in rare specialized instances, vegetable oil. Petroleum oils are usually classified as either paraffinic or naphthenic. Paraffinic oils, as the name implies, contains paraffin wax, and are the most widely used type of lubricating oil base stock. In comparison to naphthenic, paraffinic oils are more resistant to oxidation, have a lower volatility, a higher viscosity index, and are generally a better lubricant. Since naphthenic oils are essentially wax free, they have a naturally low pour points.

Synthetic based lubricants, that is, lubricants produced from man made products rather than from vegetable or refined petroleum oils, are generally superior to petroleum lubricants in most circumstances. Despite the superior performance of synthetic lubricants, their use is usually limited to severe or unusual applications due to their cost, which can be many times more than a similar petroleum product.

4.1 Oil Characteristics

Viscosity. Probably the single most important characteristic of a lubricant is its viscosity. As mentioned earlier, viscosity is a measure of a fluid's internal friction or resistance to flow. The higher viscosity a fluid has, the greater the internal resistance, and the greater its load capacity, but with the higher internal resistance, operating temperatures can rise. An oil with the correct viscosity for a particular application will be thick enough to support the load while not being so thick to cause excessive fluid friction and a corresponding increase in operating temperature.

Dynamic or absolute viscosity is defined as the ratio of shear stress to shear rate and is most commonly measured in poise or centipoise.

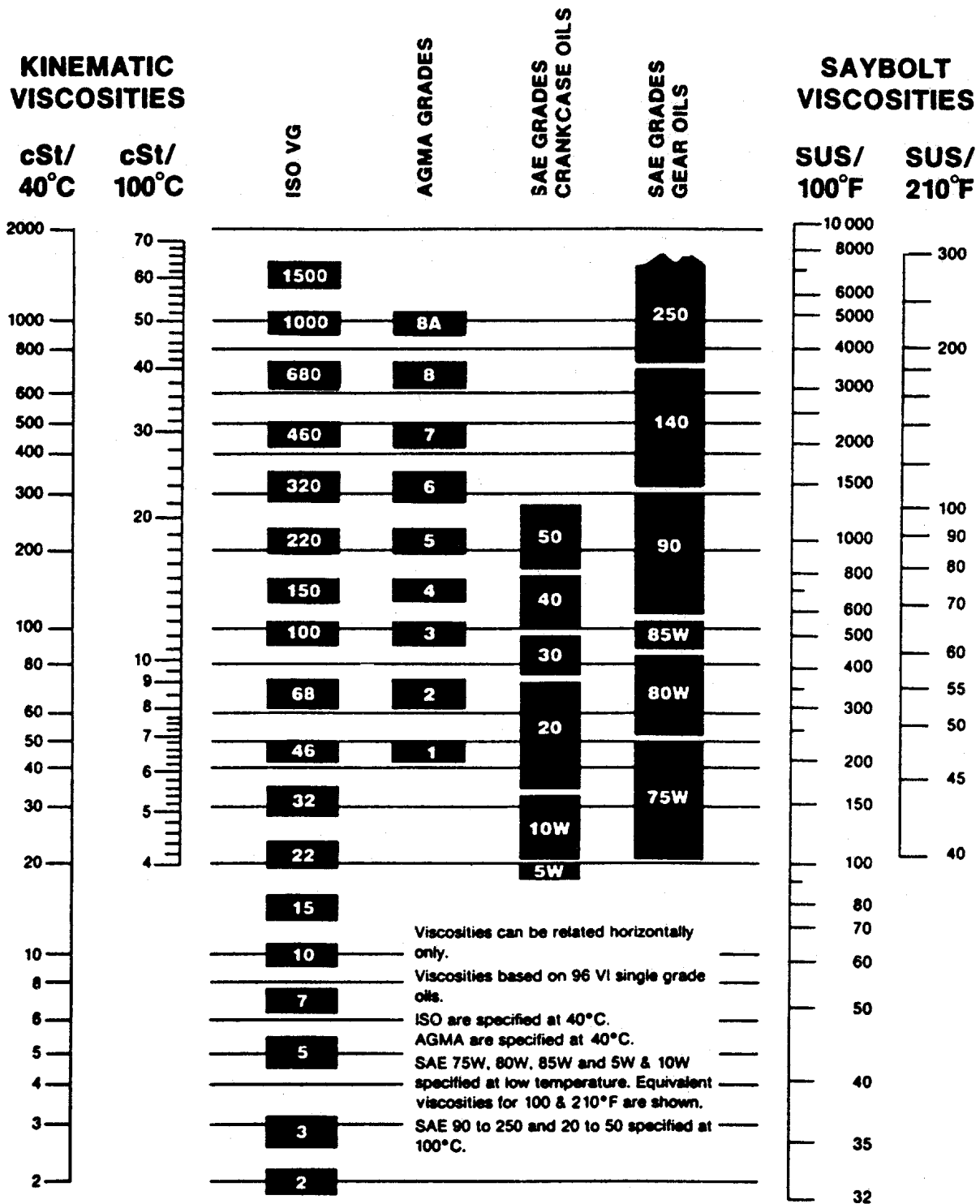
Figure 1 Illustrates this. Kinematic viscosity is the dynamic viscosity divided by the density of the lubricant and is most commonly measured in centistokes. The kinematic viscosity is related to the time required for a fixed volume of lubricant to flow through a capillary tube under the influence of gravity. The kinematic viscosity is the most common method of expressing a lubricant's viscosity.

There are many other methods for measuring and expressing the viscosity of lubricants. One common viscosity measuring system, although considered by many to be obsolete, is Saybolt Universal Seconds (SUS), or Saybolt Seconds Universal (SSU). In this system the viscosity is the amount of time, in seconds, it takes for 60 cubic centimeters of the lubricant to flow through a standard orifice at a given test temperature, usually 100 or 210° F.

Various organizations also have grading systems for lubricant viscosity. The International Standards Organization (ISO) grades are common for turbine and hydraulic oils. The Society of Automotive Engineers (SAE) has developed grades for crankcase and gear oils. It should be noted that these grades do not correspond to a specific Kinematic or Saybolt viscosity value, but to a viscosity range. **Figure 4** compares some of the more common viscosity grading systems to Kinematic and Saybolt viscosities.

Viscosity Index. An oil's viscosity index (VI) is an empirical number used to describe its viscosity-temperature relationship. An oil with a high VI indicates a relatively low change in viscosity with a change in temperature.

Pour Point. A fluid's pour point is the lowest temperature at which the fluid will flow. In paraffinic oils, the pour point is the result of the crystallization of waxy particles. In naphthenic oils, the pour point is the result of the decrease in viscosity caused by a decrease in tempera-



Viscosity Grading Systems Comparison

Figure 4

(Courtesy of Conoco Inc.)

ture. This property is important in choosing a lubricant for cold weather applications.

Flash Point. The flash point is the lowest temperature at which vapors are given off in sufficient quantity to ignite when brought into contact with a spark or flame. The flash point is not necessarily the safe upper temperature limit, but a relative indication of the fire and explosion hazard of a particular oil. The flash point can also be used as an indication of the evaporation losses that can be expected under high temperature applications.

Fire Point. The fire point is the lowest temperature at which vapors are given off in sufficient quantity to sustain combustion.

Neutralization Number. The neutralization number is a measure of the acidity of an oil and is the amount, in milligrams, of potassium hydroxide (KOH) required to neutralize one gram of oil. A relative increase in the neutralization number indicates oxidation of the oil.

4.2 Oil Compatibility

When it becomes necessary to replenish an oil lubrication system, oil that is identical to the oil already in the system should be added. Many times oils made by different manufacturers for the same service may be incompatible due to additives in the oils. The additives may react with one another causing a depletion of these additives and leaving the oil unable to perform as it was intended. If the oil originally used is unavailable, the lubricant's manufacturer should be consulted to determine what type oil can be added successfully. Any time oil is added to a system, the system should be checked frequently (i.e. bearing temperatures, signs of foaming, rust or corrosion) to insure that there is no adverse reaction between the new and existing oil.

4.3 Oil Testing and Analysis

The periodic analysis of lubricating oil can be an important part of a preventive maintenance program. Tests can measure the effects of oxidation, and detect the types and amount of various contaminants in the oil. This can be helpful in detecting problems within a lubricating system, determining whether the oil is still serviceable, and for setting up a filtering or purification schedule. By keeping track of the condition of the oil, damage to equipment due to oil deterioration can be prevented. There are a variety of tests that can be performed on an oil depending on its type and service. Some tests can be performed in the field to obtain a quick indication of an oil's condition, but since field testing is not as complete or as accurate as laboratory analysis, laboratory tests should be performed as well.

Sample Collection. In order for an oil analysis program to be successful, the oil sample drawn must be representative of oil in the system. To insure this, the sample should be drawn into clean, oil compatible containers while the equipment is in operation or immediately after shutdown. If the oil is drawn from a tap on the oil sump, let sufficient oil flow to clear stagnant oil from the tap before taking the sample. The sample should be labeled immediately, with the date the sample was taken, the source of the sample, and the type and brand name of the lubricant.

Field Tests. A visual inspection of an oil sample is the simplest type of field test. The sample to be inspected should be stored at room temperature away from direct sunlight for at least 24 hours prior to the inspection. The sample should then be checked for sediment, separated water, unusual color or cloudiness and for any unusual odors. For comparison, it is a good idea to keep a sample of new unused oil of the same type and manufacturer, stored in a sealed container in a cool dark place. The used sample can then be compared to new sample with respect to color, odor, and general appearance.

Hazy or cloudy oil may be the result of water contamination. The crackle test can be used to verify the presence of water in oil, but does not give any quantitative results. The crackle test can be conducted by making a small cup from aluminum foil, adding a few drops of the oil, and heating rapidly with a small flame. The test can also be conducted by Immersing a hot soldering iron in a sample of the oil. In either method, a audible crackling sound will be heard if water is present. Eye protection should be worn during the test as oil may splatter while being heated.

If water is found during the visual inspection, the oil should be purified and a sample of the purified oil sent to a laboratory for analysis. If sediment is found, the oil should be purified and samples of the unpurified oil and the purified oil should be sent in for analysis. In this way the sediment of the unpurified oil can be analyzed to determine its source.

The oil's neutralization number can also be determined in the field. With the exception of some motor oils, which may be alkali, most lubricating oils are essentially neutral. If an oil is found to be acidic, it is likely the result of oxidation of the oil due to extended service or abnormal operating conditions. The neutralization number of new oil is usually less than 0.08. The maximum allowable number depends on the type of oil and its service, and should be obtained from the oil manufacturer. The maximum value, is usually less than 0.5. Of greatest concern in this test is the rate of increase, not necessarily the neutralization number itself. A sudden increase in the neutralization number may indicate that the some operational problem exists or that the oil has simply reached the end of its useful life. In either case, some action is required before further deterioration and equipment damage occurs. If a large increase in the neutralization number is found or if the number exceeds the maximum allowable, the oil's manufacturer should be contacted to determine what, if anything, can be done to reclaim the oil.

Laboratory Tests. Laboratory tests should include tests for viscosity, neutralization number,

water contamination, and the identity of wear metal and other contaminants and can usually be accomplished by local laboratories or by the Applied Science Branch, D-3740, In Reclamation's Denver Office. If at all possible, the oil's manufacturer should perform tests periodically. Since the composition and additive content of oils is usually considered proprietary information, only the manufacturer can accurately determine the extent of additive depletion. The manufacturer should also be contacted anytime the tests indicate there is some question about the continued serviceability of an oil.

Test Schedule. Samples should be drawn from all guide bearings and governors annually and submitted for laboratory analysis. In addition to the annual tests, samples should be visually inspected at frequent Intervals. In most cases, annual laboratory testing is sufficient, but more frequent testing may be warranted if a visual inspection of the oil indicates the presence of water or sediment, or if previous laboratory tests had indicated a sudden increase in contaminants or oxidation products.

4.4 Oil Purification and Filtration

In order for a lubricating oil to perform properly it must be kept free of contaminants. In most hydraulic systems, an in-line filter is employed to continually filter the oil any time the system is in operation, but in most lubricating systems, the oil is filtered or purified periodically. The frequency of purification should be based on the results of the oil testing program.

Water is the most common contaminant found in hydroelectric plants and its presence in oil may promote oxidation, corrosion, sludge formation, foaming, additive depletion, and generally reduce a lubricant's effectiveness. Solid contaminants such as dirt or dust and wear particles may also be present. These solid particles may increase wear, and promote sludge formation, foaming, and restrict oil flow within the system. To remove contaminants

from the oil, it must be periodically purified. The following are some of the most common methods:

Gravity Purification. Gravity purification is simply the separation, or the settling of contaminants that are heavier than the oil. Gravity separation occurs while oil is in storage, but is usually not considered an adequate means of purification for most applications. Other purification methods should also be used. In addition to gravity separation.

Centrifugal Purification. Centrifugal purification is gravity separation accelerated by the centrifugal forces developed by rotating the oil at high speed. Centrifugal purification is an effective means of removing water and most solid contaminants from the oil. The rate of purification depends on the viscosity of the oil and the size of the contaminants.

Mechanical Filtration. Mechanical filtration removes contaminants by forcing the oil through a filter medium with holes smaller than the contaminants. Mechanical filters with a fine filter medium can remove particles as small as 1 micron, but **filtration under five microns is not recommended as many of the oil's additives will be removed.** A typical mechanical filter for turbine oil would use a 6 to 10 micron filter. The filter medium of a mechanical filter will require periodic replacement as the contaminants collect on the medium's surface.

Coalescence Purification. A coalescing filter system utilizes special cartridges to combine small, dispersed water droplets into larger ones. The larger water drops are retained within a separator screen and fall to the bottom of the filter while the dry oil passes through the screen. A coalescing filter will also remove solid contaminants by the mechanical filtration principle.

Vacuum Dehydration. A vacuum dehydration system removes water from oil through the

application of heat and vacuum. The contaminated oil is exposed to a vacuum and is heated to temperatures of approximately 100 to 140° F. The water is removed as a vapor. Care must be taken so that some of the desirable, low vapor pressure components or additives are not removed by the heat or vacuum.

Adsorption Purification. Adsorption or surface attraction purification uses an active type media, such as fullers earth, to remove oil oxidation products by their attraction or adherence to the large internal surfaces of the media. **Adsorption purification will also remove most of an oil's additives as well and should not be used for turbine oil purification.**

4.5 Oil Operating Temperature

A recommended range for the oil operating temperature for a particular application is usually specified by the equipment manufacturer. Exceeding this range may reduce the oil's viscosity to the point it can no longer provide adequate lubrication. Subjecting oil to high temperatures also increases the oxidation rate. For every 18° F (10° C) above 150° F (66° C), an oil's oxidation rate doubles which means the oil's life is essentially cut in half. This is especially critical to turbine oil in hydroelectric generating units where the oil is expected to last for years. Ideally the oil should operate between 120 to 140° F (50 to 60° C). If the oil operates consistently above this range, some problem, such as misalignment or tight bearings, may exist and should be corrected. If it is necessary to operate at higher temperatures, the oil's neutralization number should be checked more frequently. An increase in the neutralization number indicates the oxidation inhibitors have been used up and the oil is beginning to oxidize. The lubricant manufacturer should be contacted for recommendations regarding the continued use of the oil.

5. GREASE LUBRICATION

Lubricating grease is a mixture of a lubricating fluid, a thickening agent, and usually, performance enhancing additives. Petroleum oils mixed with a soap thickening agent make up the majority of the grease in use today. The soaps are formed by the reaction of animal or vegetable fats or fatty acids with strong alkalies such as calcium or sodium. Non soap thickening agents, such as modified clays and polyureas, are also used in some instances. Synthetic oils are used in severe conditions or when a normal petroleum oil is not adequate. Table 1 lists some of the common grease thickener types and their usual properties. Some of the ratings listed in this table are subjective and can vary greatly depending on the manufacturer.

The lubricating fluid, which is usually petroleum oil, is the main ingredient of all greases, making up 85 to 95 percent of the final product. While thickening agents impart some important characteristics to a grease, the oil and its additives, perform the actual lubrication. Since the base oil is the most important component of the grease, many of its characteristics, such as viscosity and pour point, influence the performance of the grease.

As moving parts come in contact with the grease, oil "bleeds" from the grease to provide either fluid film or boundary lubrication. The oil picked by the moving parts, will be lost due to evaporation or leakage so the grease must continually "bleed" to provide sufficient lubrication. Eventually the grease must be replenished or replaced.

Grease is used when it is not practical or convenient to use oil. In applications where sealing against leakage would be difficult or where the bearing is submerged in water, grease works very well. Grease also has the advantages of requiring less frequent relubrication or replenishment intervals than many oil lubricated systems and can more readily seal out dust and dirt.

5.1 Grease Characteristics

Consistency. A grease's consistency, or hardness, is a measure of its resistance to deformation by an applied force and is in most cases, a grease's most important characteristic. A grease's consistency is dependent on its base oil's viscosity and the type and amount of thickening agent used. Consistency is measured in terms of the depth, in tenths of a millimeter, that a standard cone will sink into a grease under prescribed conditions and is referred to as the penetration number. The National Lubricating Grease Institute (NLGI) has established consistency numbers, or grades, ranging from 000 (soft) to 6 (hard), corresponding to specified ranges of penetration numbers. This rating system covers most greases but there are greases available that are softer than a NLGI No. 000 or harder than a No. 6.

The consistency of a grease should be soft enough to allow easy application and provide acceptable lubrication, but not so soft to leak out of the area being lubricated. In automatic greasing systems, a grease with a consistency softer than is optimum for the lubrication of the equipment may be required so that it can be pumped through the long lines and metering valves. As with an oil's viscosity, grease consistency becomes thinner or more fluid with an increase in temperature and thicker or more solid with a decrease in temperature.

Consistency Stability. A grease's consistency may change while in use primarily due to the mechanical shearing of the thickening agent particles. The resistance to this change is referred to as Consistency Stability.

Dropping Point. A grease's dropping point is the temperature at which the grease becomes soft enough that a drop of fluid will fall from the grease. At or above the dropping point, a grease will act as a fluid. It should be noted that the dropping point is not the highest allowable operating temperature for a grease, as the

GREASE APPLICATION GUIDE

| Properties | Aluminum | Sodium | Calcium Conventional | Calcium Anhydrous | Lithium | Aluminum Complex | Calcium Complex | Lithium Complex | Polyurea | Organo-Clay |
|-----------------------------|-------------------|--------------------------|--------------------------|-----------------------|--------------------------------------|---------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|---------------------------|
| Dropping Point °F(°C) | 230 (110) | 325-350 (163-177) | 205-220 (96-104) | 275-290 (135-143) | 350-400 (177-204) | 500+ (260+) | 500+ (260+) | 500+ (260+) | 470 (243) | 500+ (260+) |
| Max. Usable Temp. °F(°C) | 175 (79) | 250 (121) | 200 (93) | 230 (110) | 275 (135) | 350 (177) | 350 (177) | 350 (177) | 350 (177) | 350 (177) |
| Water Resistance | Good to Excellent | Poor to Fair | Good to Excellent | Excellent | Good | Good to Excellent | Fair to Excellent | Good to Excellent | Good to Excellent | Fair to Excellent |
| Work Stability | Poor | Fair | Fair to Good | Good to Excellent | Good to Excellent | Good to Excellent | Fair to Good | Good to Excellent | Poor to Good | Fair to Good |
| Oxidation Stability | Excellent | Poor to Good | Poor to Excellent | Fair to Excellent | Fair to Excellent | Fair to Excellent | Poor to Good | Fair to Excellent | Good to Excellent | Good |
| Protection Against Rust | Good to Excellent | Good to Excellent | Poor to Excellent | Poor to Excellent | Poor to Excellent | Good to Excellent | Fair to Excellent | Fair to Excellent | Fair to Excellent | Poor to Excellent |
| Pumpability | Poor | Poor to Fair | Good to Excellent | Fair to Excellent | Fair to Excellent | Fair to Good | Poor to Fair | Good to Excellent | Good to Excellent | Good |
| Oil Separation | Good | Fair to Good | Poor to Good | Good | Good to Excellent | Good to Excellent | Good to Excellent | Good to Excellent | Good to Excellent | Good to Excellent |
| Appearance | Smooth and Clear | Smooth to Fibrous | Smooth and Buttery | Smooth and Buttery | Smooth and Buttery | Smooth and Buttery | Smooth and Buttery | Smooth and Buttery | Smooth and Buttery | Smooth and Buttery |
| Other Properties | | Adhesive and Cohesive | EP Grades Available | EP Grades Available | EP Grades Available, Reversible | EP Grades Available, Reversible | EP and Antwear Inherent | EP Grades Available | EP Grades Available | |
| Principal Uses | Thread Lubricant | Rolling Contact Bearings | General Uses for Economy | Military Multiservice | Multiservice Automotive & Industrial | Multiservice Industrial | Multiservice Automotive & Industrial | Multiservice Automotive & Industrial | Multiservice Automotive & Industrial | High Temp. (Freq. Relube) |

Table 1

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grease may actually start to break down far below the dropping point. The dropping point should only be used as a general indication of a grease's temperature limit. Most grease manufacturers list a usable temperature range, along with the dropping point in the specifications for a grease.

A few types of grease have the ability to return to their original consistency after temporary exposure to temperatures at, or above their dropping point. This property is referred to as reversibility.

5.2 Grease Compatibility

The mixing of two greases many times will result in a product inferior to either of the component greases. The mixture may be softer in consistency, less resistant to heat, and have a lower shear stability. When this happens, the greases are considered incompatible. Incompatibility of greases is normally a result of the incompatibility of the thickening agents of the component greases. Table 2 lists the compatibility of some of the most common types of greases. It should be noted that this table is intended only as a guide. In some instances, grease types listed

| GREASE INCOMPATIBILITY CHART | | | | | | | | | |
|------------------------------|--------|------------------|--------|---------|-----------------|------|---------|-----------------|----------|
| Grease Type | Sodium | Aluminum Complex | Barium | Calcium | Calcium Complex | Clay | Lithium | Lithium Complex | Polyurea |
| Sodium | C | I | I | I | I | I | I | I | I |
| Aluminum Complex | I | C | I | I | I | I | B | C | I |
| Barium | I | I | C | I | I | I | I | I | I |
| Calcium | I | I | I | C | I | I | B | C | I |
| Calcium Complex | I | I | I | I | C | I | I | I | I |
| Clay | I | I | I | I | I | B | I | I | I |
| Lithium | I | B | I | B | I | I | C | C | I |
| Lithium Complex | I | C | I | C | I | I | C | C | I |
| Polyurea | I | I | I | I | I | I | I | I | C |

B- Borderline Compatibility

C- Compatible

I-Incompatible

Table 2
(Courtesy of Conoco Inc.)

as compatible may be incompatible due to adverse reactions between the thickening agent of one grease and additives in the other. In rare cases, greases with the same thickening agent, but made by different manufacturers, may be incompatible due to the additives.

If it becomes necessary to change the grease type used in a piece of equipment, if at all possible, the bearing housing or the area being greased should be thoroughly cleaned to remove all of the old grease. If this is not possible, as much as possible of the old grease should be flushed out by the new grease during the initial application and the greasing frequency should be increased until it is determined that all of the old grease has been purged from the system.

5.3 Grease Application

The most common problem with the grease lubrication of antifriction bearings (ball and roller bearings) is over-lubrication. Excess grease will churn within the bearing housing, and cause excessive heat, which can soften the grease, reducing its effectiveness and lead to bearing damage. The heat can also cause the grease to expand, increasing the temperature further and create enough pressure to damage the bearing seals.

Ideally a grease lubricated antifriction bearing should be "packed" by hand so that the bearing housing is approximately one third full of grease. The bearing housing should be opened, the bearing and all of the old grease removed, and the bearing and the housing thoroughly cleaned.

Compressed air should not be used for cleaning or drying the bearing as moisture in the air may induce corrosion in the highly polished bearing surfaces. When clean, the bearing should be thoroughly packed in new grease and the bearing housing filled one third full of grease.

It is not always practical or possible to hand pack a bearing. In these cases grease guns or other high pressure device may be used. Caution should be exercised when using high pressure systems to prevent over-greasing or over-pressuring the bearing. When grease is applied using a grease gun, the relief plug, if so equipped, should be removed so that as the new grease is applied, all of the old grease is purged from the bearing housing. The machine should be operated approximately 30 minutes before the plug is replaced to allow excess grease to escape. If the bearing housing doesn't have a relief plug, grease should be added very infrequently to prevent over lubrication, and after grease is added, the pressure fitting or "zerk" should be removed to prevent pressure retention.

Grease lubricated bushings or journal bearings are not as sensitive to over-lubrication as antifriction bearings so "hand packing" is not usually necessary. The most common method of applying grease to a journal bearing is by a high pressure system. This may be a centralized, automatic system, as is used on turbine wicket gates, or it may be a simple grease gun. Over-greasing with a high pressure system will not normally damage the bearing, but it can damage seals, waste grease, and cause a mess.

6. LUBRICANT STORAGE AND HANDLING

6.1 Safety

When handled properly, most lubricants are safe, but when handled improperly, some hazards may exist. The Material Safety Data Sheet (MSDS) provides information on the potential hazards associated with a specific lubricant and should be readily accessible to all personnel involved in any way in the handling of lubricants. The lubricant's MSDS should provide information on any hazardous ingredients, physical and chemical characteristics, fire and explosion data, health hazards, and precautions for safe use.

6.2 Oil

In most powerplants, a bulk storage system with separate clean and dirty oil tanks is used to store the oil for the guide bearings and governors. At times, the clean oil tank can become contaminated by water condensation or dust or dirt in the air. To prevent the contamination of the bearing or governor oil reservoirs, the oil from the clean tank should be filtered again as it is being pumped into these reservoirs. If this is not possible, the initial oil drawn from the clean tank should be directed into the dirty oil tank to remove any settled contaminants.

The clean oil storage tank should be periodically drained and thoroughly cleaned. If the area where the storage tanks are located is dusty, it may be desirable to install a filter in the tank's vent line. If water contamination is a persistent

or excessive, a water absorbent filter, such as silica gel may be required.

Oil stored in drums, if possible, should be stored indoors, following label directions as they pertain to special precautions regarding temperature or ventilation requirements. If it is necessary to store drums outside, they should be stored on their side to prevent water or dirt from collecting on top of the drum. The bungs on the drums should always be kept tightly closed except when oil is being drawn out. If a tap or pump is installed on the drum, the outlet should be wiped clean after drawing oil to prevent dust from collecting.

6.3 Grease

Characteristics of some greases may change in storage. A grease may bleed, change consistency, or pick up contaminants during storage. Some greases may be more susceptible to the effects of prolonged storage than others, so the manufacturer or distributor should be consulted for information on the maximum shelf life of a particular grease. To be safe, no more than a one year supply of a grease should be in storage at any time. Grease should be stored in a tightly sealed container to prevent dust, moisture, or other contamination, and stored where it will not be exposed to excessive heat, such as near furnaces or heaters. Excessive heat may cause the grease to bleed and oxidize.

7. LUBRICANT SELECTION

When choosing a lubricant for a particular piece of equipment, the equipment manufacturer's operation and maintenance manual should be consulted. The operation and maintenance manual will usually outline the required characteristics of the lubricants as well as a recommended schedule for replacement or filtering. When the maintenance manual is not available, lubricant manufacturers and distributors can usually be of assistance. They will usually request pertinent information on the equipment, such as operating speed, frequency of operation, operating temperature, and any other special or unusual conditions, so that a lubricant with the proper characteristics can be chosen. Some discretion should be used when dealing with a lubricant salesperson to prevent purchasing an expensive lubricant with capabilities in excess of what is required.

When ever possible lubricants should be purchased that can be used in several applications. By limiting the number of lubricants on site, the chance of mixing different lubricants or using the wrong lubricant is minimized.

There are a number of tests which have been developed to define and measure the properties of lubricants. Most of these tests have been standardized by the American Society for Testing and Materials (ASTM). Some of the more common tests and their procedures are described in the Appendix. The properties determined by these tests can be very helpful in comparing relative performance of several lubricants but it should be noted that many of these tests have little correlation to actual service conditions. When selecting a lubricant, the test procedures for the required properties should be reviewed so that relevance of the test is kept in perspective.

7.1 Unit Guide and Thrust Bearings

Under normal conditions, the lubricating oil for a hydroelectric unit's guide and thrust bearings experiences relatively mild service, but it is expected to have a long service life. In order to have a long life, a high quality oil is required with various additives to enhance and maintain its quality.

In most powerplants, a highly refined turbine oil is used in the bearings. [Table 3](#) lists some typical specifications for turbine oils. The oil should be rust and oxidation inhibited with an antifoam additive. The oil should also be resistant to emulsification and separate readily from water. Antiwear or extreme pressure additives are not required or desired.

The recommended oil viscosity is usually supplied by the equipment manufacturer and depends on the operating speed, load, and temperature as well as the bearing clearances. The most common viscosities used are the ISO viscosity grades 32, 46, and 68.

7.2 Hydraulic Systems

A hydraulic fluid's primary purpose is to transmit power. To accomplish this effectively, the fluid must be incompressible and readily flow through the system. The fluid must also have sufficient viscosity to seal and lubricate the components of the hydraulic system. There are a variety of fluids capable of performing these functions but the most satisfactory hydraulic fluid is usually oil.

A hydraulic oil has many of the same requirements as the lubricating oil used in the unit bearings and in many cases the same oil can be used. If the system uses a gear pump, operates at pressures less than 1000 psi, and has similar viscosity requirements, a turbine oil can func-

| TYPICAL SPECIFICATIONS FOR TURBINE AND HYDRAULIC OIL (Military Specification Mil-H-17672) | | | | |
|---|---------------------|-------------|-------------|---------------------|
| Characteristics | ISO VISCOSITY GRADE | | | ASTM TEST NO. |
| | 32 | 46 | 68 | |
| Viscosity, centistokes at 40°C (104°F) | 28.8 - 35.2 | 41.4 - 50.6 | 61.2 - 74.8 | D 445 |
| Viscosity Index, minimum | 94 | 94 | 94 | D 2270 |
| Pour Point, °C (°F), maximum | -29 (-20) | -23 (-10) | -18 (0) | D 97 |
| Flash Point, °C (°F), minimum | 157 (315) | 163 (325) | 171 (340) | D 92, D 341 |
| Neutralization Number, maximum | 0.02 | 0.02 | 0.02 | D 974 |
| Rust Preventative Characteristics in the Presence of Water | Pass | Pass | Pass | D 665 Proced. B |
| Foam Characteristics: Tendency/Stability | | | | D 892 Option A |
| Sequence 1, mL maximum | 65/0 | 65/0 | 65/0 | |
| Sequence 2, mL maximum | 65/0 | 65/0 | 65/0 | |
| Sequence 3, mL maximum | 65/0 | 65/0 | 65/0 | |
| Emulsion Test, After 30 Minutes Settling Time Oil Layer, maximum | 40 mL | 40 mL | 40 mL | D 1401 |
| Oxidation Test, Time Required in Hours to Reach Neutralization Value of 2.0 mg KOH After 1000 hours: | 1000 | 1000 | 1000 | D 943 |
| Total Sludge, mg maximum | 100 | 100 | 100 | |
| Total Iron, mg maximum | 100 | 100 | 100 | |
| Total copper, mg maximum | 100 | 100 | 100 | |

Table 3

tion very well as a hydraulic oil. In systems that operate over 1000 psi or use a piston or sliding vane pump, a fluid with an anti-wear additive is usually required. Where the system operates in an area of great temperature extremes, an oil with a high viscosity index might be required to provide desirable high and low temperature viscosity characteristics.

In some instances, although very rarely in a hydroelectric plant, a fire resistant hydraulic fluid may be required. These fluids are usually either a water based or a synthetic fluid. In either case, the system must be designed specifically for the fluid it will use. Water based fluids have a very low viscosity and the synthetic fluids many times are not compatible with most seals.

7.3 Hydraulic Governor Systems

A hydraulic governor system is simply a hydraulic system and in most cases can use the turbine oil used in the unit bearings. In some cases, such as low plant temperatures or extremely long control lines, a lighter viscosity oil may be required.

7.4 Wicket Gate Bushings

Grease for the wicket gate bushings must be adhesive, water resistant, able to withstand high bearing pressures, and of a consistency that can be pumped at the lowest temperature encountered. Usually a grease with extreme pressure or antiwear capabilities is specified. The grease's dropping point has little relevance in this case.

There are a number of different greases that have shown to provide adequate lubrication in wicket gate bushings. Most of these greases have a lithium or calcium soap base, but it should be noted that not all lithium or calcium based greases are acceptable. The additives contained in a grease enhance or impart many of the grease's characteristics, so when select-

ing a grease, all of its characteristics should be considered. While a very adhesive grease may be desirable, the adhesiveness may make it very difficult to pump through a centralized system. Conversely, a grease that is easily pumped may not stay in the bushing. Some compromise is usually required.

7.5 Gears

Gears vary greatly in design and in their requirements for lubrication. When selecting a lubricant for any gear application the type of gears, and operating conditions, such as speed, load, and temperature must be considered. Enclosed gears, that is gears encased in an oil tight housing usually will use a mineral oil with various additives depending on the conditions. Rust, oxidation, and foam inhibitors are common, as are extreme pressure additives where loads are severe.

Worm gears are a special case as the action between the worm and its mating gear is sliding rather than the rolling action found in most gears. The sliding action allows fluid film lubrication to take place. Another difference is the fact that the mating gears, that is worm and the bull gear, are usually made of dissimilar materials which reduces the chance of galling and reduces friction. Extreme pressure additives are usually not required for worm gears but lubrication can be improved by oiliness additives.

A highly adhesive lubricant is required for most open gear applications. An open gear lubricant must resist being thrown off by centrifugal force or being scraped off by the action of the gear teeth. Most open gear lubricants are heavy oils, many times asphalt based, or soft greases. Depending on the service conditions, oxidation inhibitors or extreme pressure additives may be added. As these lubricants are very adhesive, they also attract dust and dirt. These contami-

nants can act as abrasives if the gears are not periodically cleaned.

7.6 Wire Rope

The life of a wire rope can be extended through the proper application of the correct lubricant. The exception to this, is wire rope operating in an extremely dirty or dusty environment where abrasives can cling to the lubricant and cause accelerated wear.

To be effective, the lubricant must penetrate into the rope to provide lubrication between the individual wires and strands. It also must provide lubrication externally to reduce friction between the rope and sheaves or drum, and it should act as a sealant to prevent corrosion. The lubricant coating should not interfere with the visual inspection of the rope for broken wires or other damage.

Many times a light mineral oil, such as a S.A.E. 10 motor oil, is used to lubricate wire rope. The advantages of such a light oil is that it can be applied cold and it will penetrate into the rope easily. The main disadvantage of a light oil is that it will work out of the rope just as easily as

it works in and frequent application will be required.

Heavy, adhesive lubricants can provide longer lasting protection, but most require heating prior to application to provide proper penetration. A heavy lubricant, when properly applied, will not only provide internal lubrication, but also provide a durable outer coating to prevent corrosion and keep dust and abrasives out of the rope.

The lubricant can be applied by brush, spray, or dripped on, or, preferably, by passing the rope through a heated reservoir filled with the lubricant. Prior to applying the lubricant it is important to clean any accumulated dirt, dust or rust from the rope, as they can prevent the lubricant from penetrating properly. The lubricant should be applied to the entire circumference of the rope and the rope slowly wound on and off the drum several times to work the lubricant into the rope. If the lubricant is being applied by hand it may be helpful to apply the lubricant as it passes over a sheave since the rope's strands are spread by the bending and the lubricant can penetrate more easily.

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Appendix

ASTM LUBRICANT TESTS

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DEMULSIBILITY

ASTM D 1401 and ASTM D 2711

In the petroleum industry, the term emulsion usually applies to an emulsion of oil and water. Though mutually soluble only to a slight degree, these substances can, under certain circumstances, be intimately dispersed in one another to form a homogeneous mixture. Such a mixture is an oil-water emulsion, and it is usually milky or cloudy in appearance.

Commercial oils vary in emulsibility. A highly refined straight mineral oil resists emulsification. Even after it has been vigorously agitated with water, an oil of this type tends to separate rapidly from the water when the mixture is at rest. Emulsification can be promoted, however, by agitation and by the presence of certain contaminants or ingredients added to the oil. The more readily the emulsion can be formed and the greater its stability, the greater the emulsibility of the oil. Some products, such as soluble cutting fluids, require good emulsibility and are formulated with special emulsifying agents.

With many other products, however, such as turbine oils and crankcase oils, the opposite characteristic is desired. To facilitate the removal of entrained water, these products must resist emulsification. The more readily they break from an emulsion, the better their demulsibility.

Two tests for measuring demulsibility characteristics have been standardized by the ASTM. The older of the two is ASTM method D 1401, which was developed specifically for steam turbine oils having viscosities of 150-450 Saybolt seconds at 100° F. It can be used for oils of other viscosities if minor changes in the test procedure are made. This method is the one recommended for use with synthetic oils.

The second method, ASTM D 2711 is designed for use with R&O (rust and oxidation inhibited) oils. It can also be used for other types of oils,

although minor modifications are required when testing EP (extreme pressure) oils.

Test Procedures

ASTM D 1401: A 40-ml sample of oil and 40 ml of distilled water are put into a 100-ml graduate. The mixture is stirred for 5 minutes while maintained at a temperature of 130° F. The time required for separation of the emulsion into its oil and water components is recorded. If, at the end of an hour, 3 or more milliliters of emulsion still remain, the test is discontinued and the milliliters of oil, water, and emulsion are reported. The 3 measurements are presented in that order and are separated by hyphens. Test time, in minutes, is shown in parenthesis.

ASTM D 2711: A 405-ml sample of oil and 45 ml of distilled water, are stirred together for 5 minutes in a special graduated separator funnel, while maintained at 180° F. After a 5-hour settling period, a 50-ml sample drawn from near the top of the oil layer is centrifuged to determine the "percent water in the oil." The "milliliters of free water" is also measured and reported. Then the mixture is siphoned off until only 100 ml remain in the bottom of the funnel. This is centrifuged and the milliliters of water and of emulsion are reported. The amount of water from this step is added to the amount of free water and the "total water" is reported.

When used to test EP gear oils, amount of oil is reduced to 360 ml while the amount of water is increased to 90 ml.

Navy Emulsion test: This procedure is similar to ASTM D 1401. Measurements are made after a 1-hour settling period (for oil tested at 130° F) or after a 1/2-hour settling period (for oils tested at 180° F), and the sample may be considered to pass if the emulsion does not exceed 3 milliliters.

Significance of Demulsibility Tests: In many applications, oil is exposed to contamination by water condensed from the atmosphere. With turbine oils, exposure is even more severe, since the oil tends to come in contact with condensed steam.

Water promotes the rusting of ferrous parts and accelerates oxidation of the oil. For effective removal of the water, the oil must have good demulsibility characteristics.

Steam cylinder oils that serve in closed systems require good emulsibility for the opposite reason: to facilitate removal of oil from the condensate, so that oil is kept out of the boiler.

Hydraulic fluids, motor oils, gear oils, diesel engine oils, insulating oils, and many similar petroleum products must resist emulsification. Oil and water must separate rapidly and thoroughly.

Either of the ASTM methods is suitable for evaluating the demulsification properties both of inhibited and uninhibited oils. However, correlation with field performance is difficult. There are many cases where the circulating oil is operating satisfactorily in the field, but fails the demulsibility test in the laboratory. Hence, it must be recognized that these laboratory test results should be used in conjunction with other facts in evaluating an oil's suitability for continued service.

DROPPING POINT OF GREASE ASTM D 566 and ASTM D 2265

It is often desirable to know the temperature at which a particular lubricating grease becomes so hot as to lose its plastic consistency. Being a mixture of lubricating oil and thickener, grease has no distinct melting point in the way that homogeneous crystalline substances do. At some elevated temperature, however, the ordinary grease becomes sufficiently fluid to drip. This temperature is called the dropping point and can be determined by the ASTM Method D 566--"Dropping Point of lubricating Grease" and ASTM Method D 2265--"Dropping Point of Lubricating Grease of Wide Temperature Range."

Apparatus: Chromium-plated brass grease cup--with small orifice at bottom.

Test tube--designed to hold grease cup about 3/4" above bottom.

2 Thermometers--one for grease cup, one for the heat source.

Source of heat--oil bath - ASTM D 566; Aluminum Block oven - ASTM D 2265.

Test Procedures

ASTM D 566--The grease cup is filled with the grease to be tested and then placed in the test tube with the thermometer and stopper inserted. The test tube is then submerged in the oil bath. The bath temperature is increased until a drop of material (grease or oil) falls from the orifice at the bottom of the cup. The thermometer readings for the oil bath and the grease are recorded at this instant. The average of the two temperatures is reported as the dropping point of the grease.

ASTM D 2265--This test is the same as ASTM D 566 except that this method provides for heating with an aluminum block oven. The oven makes it possible to measure dropping points up to 625° F, higher than was possible with the oil bath.

Significance of Results: Since both these tests are held under static conditions, the results have only limited significance with respect to service performance. Many other factors such as time exposed to high temperatures, changes from high to low temperatures, evaporation resistance and oxidation stability of the grease, frequency of lubrication, and the design of the lubricated mechanism are all influences that affect the maximum usable temperature for the grease.

Though both dropping point and consistency are related to temperature, the relationships follow no consistent pattern. The fact that a grease does not liquify at a particular temperature gives

no assurance that its consistency will be suitable at that temperature. However, the dropping point is useful in identifying the grease as to type and for establishing and maintaining bench marks for quality control.

One of the weaknesses of either procedure is that a drop of oil may separate and fall from the grease cup at a temperature below that at which the grease fluidizes. This would then give an erroneous indication of the actual temperature at which the grease becomes soft enough to flow from the cup.

FLASH AND FIRE POINTS-OPEN CUP ASTM D 92

The flash point and the fire point of a petroleum liquid are basically measurements of flammability. The flash point is the minimum temperature at which sufficient liquid is vaporized to create a mixture of fuel and air that will burn if ignited. As the name of the test implies, combustion at this temperature is only of an instant's duration. The fire point, however, runs somewhat higher. It is the minimum temperature at which vapor is generated at a rate sufficient to sustain combustion. In either case, combustion is possible only when the ratio of fuel vapor to air lies between certain limits. A mixture that is too lean or too rich will not burn.

The practice of testing for flash and fire points was originally applied to kerosene to indicate its potentiality as a fire hazard. Since then, the scope has been broadened to include lubricating oils and other petroleum products. Though it has become customary to report flash point (and sometimes fire point) in lubricating oil data, these properties are not as pertinent as they might appear. Only in special instances does a lubricating oil present any serious fire hazard. Being closely related to the vaporization characteristics of a petroleum product, however, flash and fire points give a rough indication of

volatility and certain other properties.

The fire point of a conventional lubricating oil is so closely associated with this flash points, that is generally omitted from inspection data. For the ordinary commercial products, the fire point runs about 50° F above the flash point. Fire and flash points are not to be confused, however, with auto-ignition temperature, which is an entirely different matter. Auto-ignition deals, not so much with volatility, as with the temperature necessary to precipitate a chemical reaction, combustion, without an external source of ignition. Though a more volatile petroleum product may be expected to have lower flash and fire points than one that is less volatile, its ASTM auto-ignition temperature is generally higher.

Apparatus: The oil sample is contained in a precisely specified brass cup that rests on a metal plate. Under the plate, a source of heat is provided, and a thermometer in the cup indicates the temperature of the sample. A small gas igniting torch is used to test the air-vapor mixture for flammability. Length of the fire-point burning period is checked with a stop watch.

Procedure: From a temperature 100° F or more below its anticipated flash point, the sample is heated at a prescribed rate. At each multiple of 5° F temperature rise, the lighted torch is passed over the top of the cup. The test for flash point is completed when the torch produces a flash from the vaporized portion of the sample.

The same procedure is extended to determine the fire point. When the flame produced by igniting the mixture of air and vaporized oil continues for at least 5 seconds, the fire point has been reached. For either test, it should be obvious that complete freedom from drafts is essential to prevent excessive dissipation of the vaporized liquid. For precision and consistent results, the test is usually carried out in a darkened room so that flash can be more readily observed.

Reporting The Results: Flash point is reported as the temperature at which flash fire occurs, the fire point is reported as the temperature at which the flame persists for 5 seconds or more.

Significance Of Test Results: To appreciate the significance of flash point and fire point test results, one must realize what the tests measure. It is necessary to understand how a combustible air-fuel mixture is created.

For all practical purposes, a petroleum liquid does not burn as such, but must first be vaporized. The vapor mixes with the oxygen in the air, and, when sufficient concentration of the vapor is reached, the mixture may be ignited, as by a spark or open flame. The mixture can be ignited only if the concentration of fuel vapor in the air is more than about 1% or less than about 6% by volume. A confined mixture containing more than 6% fuel vapor becomes a practical explosion hazard only if it is vented to admit a greater portion of air.

The significance of flash- and fire-point value lies in the dissimilarity that exists in the volatility characteristics of different petroleum liquids. Even among lubricating oils of comparable viscosity, there are appreciable variations in

volatility, and hence in flash and fire points. In general, however, the storage and operating temperatures of lubricating oils are low enough to preclude any possibility of fire. Among the exceptions to this situation are such products as quenching and tempering oils, which come in direct contact with high temperature metals. Heat-transfer oils, used for heating or cooling, may all reach temperatures in the flash- and fire-point ranges. Similarly, in the evaluation of roll oils, which are applied in steel mills to hot metal sheets from the annealing oven, fire hazard may likewise be a consideration. In many of these cases, however, auto-ignition temperature is of greater significance. At the auto-ignition temperature, as determined by test, fire is not merely a possibility, it actually occurs spontaneously, i.e., without ignition from any outside source.

Since flash and fire point are also related to volatility, however, they offer a rough indication of the tendency of lubricating oils to evaporate in service. It should be apparent that lower flash and fire points imply a greater opportunity for evaporation loss. The relationship between test results and volatility is by no means conclusive, however. The comparison is distorted by several additional factors, the most important of which is probably the manner in which the oil is produced.

The relationship between flash and fire point, on the one hand, and volatility, on the other, is further distorted by differences in oil type. For a given viscosity, a paraffinic oil will exhibit higher flash and fire points than other types and may be recognized by these test results. Paraffinicity may also be indicated by a high viscosity index or by a high pour point.

Fire and flash points are perhaps of greater significance in the evaluation of used oils. If an oil undergoes a rise in flash or fire point in service, loss by evaporation is indicated. The more volatile components have been vaporized, leaving the less volatile ones behind; so an increase in viscosity is apparent. An excessive

increase in viscosity may so alter lubricating properties that the oil is no longer suitable for its intended application.

If, on the other hand, the flash or fire points drop in service, contamination is to be suspected. This may happen to motor oils that become diluted with unburned fuel. Gasoline or heavier

fuels in the crankcase reduce the viscosity of the oil, and bearings and other moving parts may be endangered by excessive thinning of the lubricant. These fuels, being more volatile than the oil, lower the flash and fire points of the mixture. So the flash- or fire-point test on used oils constitutes a relatively simple method for indicating the presence of dilution.

FOAMING CHARACTERISTICS OF LUBRICATING OILS ASTM D 892

Foaming in an industrial oil system is a serious service condition that may interfere with satisfactory system performance and even lead to mechanical damage.

While straight mineral oils are not particularly prone to foaming, the presence of additives and the effects of compounding change the surface properties of the oils and increase their susceptibility to foaming when conditions are such as to mix air with the oils. Special additives impart foam resistance to the oils and enhance their ability to release trapped air quickly under conditions that would normally cause foaming

Apparatus: The foaming test apparatus consists of special 1000-ml graduated cylinders, air inlet tubes, and fused alumina gas diffuser stones. Also two constant-temperature water baths (one at 75° F and one at 200° F), a compressed air supply, drying tower 300 mm in height, flowmeter, wet-test meter or other gas-volume measuring device, stopwatch or timer, and thermometers meeting ASTM specifications.

Preparation of Apparatus: Thorough cleansing with the prescribed solvents and drying of the test cylinders and gas diffuser stones are required for proper preparation of the apparatus.

Procedure

a) Pour a 190-ml sample of the oil to be tested, which has been previously heated to 120° F and cooled to 75° F, into a graduated cylinder, immersed at least to the 900-ml mark in the 75°F constant-temperature bath. Immerse a diffuser stone in the sample, adjust air flow to 95 ml per minute and, then, connect the air-inlet tube to the stone and, force air through the stone for 5 minutes. Then disconnect the tube and immediately record the volume of foam. Allow the sample to stand for 10 minutes and again record the foam volume.

b) Pour a 180-ml sample of the oil being tested into a graduated cylinder, immersed at least to the 900-ml mark in the 200° F bath. When the sample reaches the bath temperature, insert a clean diffuser stone and proceed as with the previous sample, recording foam volume at the end of the blowing and settling period.

c) Collapse any foam remaining after the 200° F test by stirring. Remove the sample from the bath and let cool to a temperature below 110° F. Then place the cylinder in the 75° F bath. Insert a diffuser stone and repeat the above procedure.

Reporting the Results: The test results are reported as volume of foam, in ml, at the end of the 5-minute blowing period, and at the end of the 10-minute settling period, for the three dif-

ferent test conditions: sample at 75° F, sample at 200° F, and sample at 75° F having been cooled from the test at 200° F. The foam volume at the end of the blowing period is a measure of the foaming tendency of the oil, while the foam volume at the end of the settling period (which is usually zero) is a measure of the stability of the foam.

Significance: Foaming consists of bubbles that rise quickly to the surface of the oil, and is to be distinguished from air entrainment, consisting of slow-rising bubbles dispersed throughout the oil. Both these conditions are undesirable, and are often difficult to distinguish due to high flow rates and turbulence in the system. These two phenomena are affected by different factors and are considered in separate laboratory tests. The primary causes of foaming are mechanical, essentially an operating condition that tends to produce turbulence in the oil in the presence of air. The current trend in hydraulic oil systems,

turbine oil systems, and industrial oil systems of every kind is to decrease reservoir sizes and increase flow rates. This trend increases the tendency for foaming in the oils.

Contamination of the oil with surface-active materials, such as rust preventives, detergents, etc., can also cause foaming.

Foaming in an industrial oil is undesirable because the foam may overflow the reservoir and create a nuisance, and the foam will decrease the lubrication efficiency of the oil, which may lead to mechanical damage.

Antifoaming additives may be used in oils to decrease foaming tendencies of the oil. However, many such additives tend to increase the air entrainment characteristics of an oil, and their use requires striking a balance between these two undesirable phenomena.

FOUR-BALL WEAR AND EP TESTS ASTM D 2266 and ASTM D 2596

Each of the tests described here is designed to evaluate a different load-carrying characteristic of lubricating grease or oil. The information provided by these tests is often used for quality control and to aid in the selection of lubricants for industrial applications.

Both tests employ similar equipment and mechanical principles. Four 1/2-inch steel balls are arranged with one ball atop three others, the three lower balls are clamped together to form a cradle, upon which the fourth ball rotates on a vertical axis.

General Descriptions of Tests: The 4-Ball Wear Test (ASTM D 2266) is used to determine the relative wear-preventing properties of lubricants on sliding metal surfaces operating under boundary lubrication conditions. The test is

carried out at a specified speed, temperature, and load. At the end of a specified period, the average diameter of the wear scars on the three lower balls is measured and reported.

The 4-Ball EP Test (ASTM D 2596) is designed to evaluate performance under much higher unit loads than applied in the 4-Ball Wear Test, hence the designation EP (extreme pressure). The 4-Ball EP Tester, of a slightly different design and construction from the 4-Ball Wear Tester, is the apparatus used. In this test, the steel ball is rotated at constant speed against three other steel balls. Temperature is not controlled. The loading is increased at specified intervals until the rotating ball seizes and welds to the other balls. At the end of each interval, the scar diameters are measured and recorded. Two values from the EP Test are generally re-

ported--Load Wear Index (formerly Hertz Mean Load) and Weld Point. Load Wear Index (LWI) is a measure of the ability of a lubricant to prevent wear at applied loads. Weld Point is the lowest applied load in Kilograms at which either the rotating ball seizes and then welds to the three stationary balls, or at which extreme scoring of the three stationary balls results. It indicates the point at which the extreme pressure limit of the lubricant is exceeded.

Apparatus and Materials: The 4-Ball Wear Tester and the 4-Ball EP Tester are special devices available from laboratory supply houses. The four steel balls (1/2-inch diameter) in both tests are of ball-bearing SAE 52100 chrome alloy steel. For cleaning and preparation of each apparatus, an Stoddard solvent conforming to the ASTM D 485 specification, and hexane conforming to ASTM D 1836 are used.

Modifications of the ASTM Wear Test procedure have also been introduced, in which bronze balls have been substituted for the 3 stationary steel balls, Discs of other materials, held by a special stationary clamp, have also been used. Wear measurements of steel-on-bronze, aluminum, nylon, etc. can thus be determined. These modifications are not included in the ASTM method.

A microscope, preferably binocular with micrometer eyepiece, is required in each test for measuring scar diameter.

Wear Test Procedure: The steel test balls and surfaces of the 4-Ball Wear Tester are thoroughly cleaned, first with Stoddard solvent, then with hexane.

One of the steel balls is then placed in the chuck of the Wear Tester. A small amount of the lubricant is placed in the ball pot of the tester, and the three remaining balls are placed in the pot. The balls are locked into position and the pot is filled with lubricant. The 4-Ball Wear Tester is then set for operation under the specified conditions. ASTM suggests 1200 rpm, a 40-kg load, temperature of 167° F, for a duration of 60

minutes, although tests are often run under different conditions. Heat is applied by an element within the tester, and then the specified operating temperature has been reached, the motor is turned on and rotation begins. At the end of the test period, the motor is turned off and the ball pot is removed.

The three stationary balls are washed with Stoddard solvent and hexane to remove the oil or grease. Using the microscope, the diameter of the wear scar on each ball is measured to the nearest 0.01 mm. Another set of measurements across each scar, 90 degrees from the first, is then made. The test conditions, rpm, load, temperature, and time, must also be reported.

EP Test Procedure: Preparation for the 4-Ball EP Test is similar to that for the Wear test. The lubricant is first brought to room temperature (80 ± 15° F). At a speed of 1770 - 60 rpm, and under a specified load, the first run begins.

The determination of Load Wear Index in the EP Test requires 11 runs: 10 of 10 seconds duration prior to welding, and one run at which welding occurs. A progressively heavier load is applied on each run and the scars on the 3 fixed balls are measured, as above, each time. In testing a lubricant of unknown EP properties, choice of the first load is by chance. Therefore, it is probable that the balls will seize and weld before 10 runs have been completed. Consequently, after this weld point is reached and recorded, additional runs at successive loadings below the weld point are made until 10 sets of scar measurements without welding have been obtained.

For each run, the applied weight, multiplied by the lever arm, is divided by the average of the 6 scar measurements. The resulting quotient is corrected for the elastic deformation of the ball surfaces due to static loading. This yields the "corrected load."

The Load Wear Index and Weld Point, described above, are recorded and reported.

Significance of the Tests: Under standardized conditions, the 4-Ball Wear Test provides a means for comparing the relative anti-wear properties of lubricants. It is not possible to directly compare the results of two tests run under different conditions, so operating conditions should always be reported with the test results. No correlation has yet been established between the 4-Ball Wear Test and field service, so individual results should not be used to predict field performance.

The 4-Ball EP Test is used in lubricant quality control, and to differentiate between lubricants having low, medium, and high extreme pressure qualities. Judgment of the relative EP properties of two oils or two greases should not be made

on the basis of results differing by less than the repeatability or reproducibility of the test. The results of the EP Test do not necessarily correlate with actual service results. Test results should not be used to predict field performance unless other lubricant properties are also taken into consideration.

Using Wear and EP Tests Together: In comparing the capabilities of various lubricants, the results of both the EP and Wear Test should be considered; this is particularly true if additives or grease thickeners are unknown or are widely dissimilar. Lubricants that have good extreme pressure properties may not be equally effective in reducing wear rates at less severe loads, and conversely.

GREASE CONSISTENCY ASTM D 217 and D 1403

The consistency of a lubricating grease is defined as its resistance to deformation under an applied force--in other words, its relative stiffness or hardness. The consistency of a grease is often important in determining its suitability for a given application.

Grease consistency is given a quantitative basis through measurement with the ASTM Cone Penetrometer. The method consists of allowing a weighted metal cone to sink into the surface of the grease, and measuring the depth to which the point falls below the surface. This depth, in tenths of millimeters, is recorded as the penetration, or penetration number, of the grease. The softer the grease, the higher its penetration.

The ASTM D 217 method recognizes five different categories of penetration, depending on the condition of the grease when the measurement is made. Undisturbed penetration is determined with the grease in its original container. Unworked penetration is the penetration of a sample which has received only minimum dis-

turbance in being transferred from the sample can to the test cup. Worked penetration is the penetration of a grease sample that has been subjected to 60 double strokes in a standard grease worker (to be described). Prolonged worked penetration is measured on a sample that has been worked the specified number of strokes (more than 60), brought back to 77° F, then worked an additional 60 double strokes in the grease worker. Block penetration is the penetration of a block grease--a grease hard enough to hold its shape without a container. All the above penetrations are determined on samples that have been brought to 77° F.

Apparatus and Materials: The ASTM Cone Penetrometer consists of a metal cone of specified weight and dimensions, an adjustable assembly, and a depth indicator.

The standard grease worker is a motor-driven device consisting of a container fitted with a perforated plunger, which moves up and down

in order to "work" the sample in the container. One cyclic movement of the plunger up and down is known as a "double stroke." The grease worker is fitted with a thermometer to provide a check on the sample temperature.

Additional apparatus includes a water bath for bringing the grease to the proper temperature, and a standard cutter for use in cutting samples of block grease.

Procedure: The initial procedure depends on the type of penetration to be determined. Undisturbed penetration requires only the opening of the grease container; unworked penetration requires transfer of the sample to the test cup. Worked and prolonged worked penetrations involve first the transfer of the sample to the cup, followed by the working procedure. Block penetration requires the cutting of a sample with the grease cutter. Sample size should be about 1 pound for most penetration determinations. For block penetration, a 2-inch cube is the required sample. Samples are brought to 77° F in either the water bath or an air bath (for block penetration) before penetration is measured.

Following this initial procedure, the sample is placed on the penetrometer platform. The cone is placed in the zero position with its tip just touching the surface of the sample. The cone is released and allowed to drop for 5 seconds. The penetration is read on the indicator in tenths of a millimeter (A penetration of 200 means that the cone moved 20.0 millimeters into the grease). This procedure is performed three times for each determination; the average of the 3 readings is recorded as the penetration.

When only a small amount of grease can be obtained, an alternate cone penetration method is available. ASTM D 1403, "Cone Penetration of Lubricating Grease Using One-Quarter and One-Half Scale Cone Equipment," may be used for samples as small as 5 grams.

Significance: If a grease is too soft, it may not stay in place, resulting in poor lubrication. If a grease is too hard, it will not flow properly, and either fail to provide proper lubrication or cause difficulties in dispensing equipment. These statements sum up the reasons for classifying greases by consistency. Penetration numbers are useful for classifying greases according to the consistencies required for various types of service, and in controlling the consistency of a given grade of grease from batch to batch.

| NLGL Grade | Worked Penetration Range mm/10 |
|------------|-----------------------------------|
| 000 | 445-475 |
| 00 | 400-430 |
| 0 | 355-385 |
| 1 | 310-340 |
| 2 | 265-295 |
| 3 | 220-250 |
| 4 | 175-205 |
| 5 | 130-160 |
| 6 | 85-115 |

The National Lubricating Grease Institute has classified greases according to their worked penetrations. These NLGI grades, shown in the accompanying table, are used for selection of greases in various applications.

In comparing greases, worked and prolonged worked penetrations are generally the most useful values. The change in penetration between the 60-stroke value and prolonged worked value is a measure of grease stability. Prolonged worked penetrations should report the amount of working (10,000 and 100,000 strokes are most common) in order to be useful.

Unworked penetrations often appear in specifications and in grease product data, but are of limited practical value. No significance can be

attached to the difference between unworked and worked penetration. Undisturbed penetration is useful mainly in quality control.

NEUTRALIZATION NUMBER ASTM D 664 and D 974

Depending on its source, additive content, refining procedure, or deterioration in service, a petroleum oil may exhibit certain acid or alkaline (base) characteristics. Data on the nature and extent of these characteristics may be derived from the product's neutralization number, or "neut number," as it is commonly known. The two principal methods for evaluating neut number are ASTM D 664 and ASTM D 974. Although respective test results are similar, they are not identical, and any reporting of results should include the method by which they are obtained.

Acidity and Alkalinity: Acidity and alkalinity are terms related to dissociation, a phenomenon of aqueous solutions. Dissociation is a form of ionization, the natural breaking up of some of the molecules into positive and negative ions. If the chemical composition of the aqueous solution is such that it yields more hydrogen ions (positive) than hydroxyl ions (negative), the solution is considered acid: an excess of hydroxyl ions on the other hand results in a solution that is considered to be basic or alkaline. The greater the excess, the more acid or alkaline the solution, as the case may be. If the hydrogen and hydroxyl ions are in equal concentration, the solution is, by definition, neutral.

Titration: Since acidity and alkalinity are opposing characteristics, an acid solution can be neutralized (or even made alkaline) by the addition of a base. The converse is also true. In either case, neutralization can be accomplished by titration, the gradual addition of a reagent until a specified end point is reached. The

amount of acid or base materials in a solution can thus be measured in terms of the quantity of added reagent. Being non-aqueous, however, petroleum oils cannot truly be said to be acid or alkaline. Nevertheless, they can be modified to exhibit these properties by addition of water--plus alcohol to extract oil-soluble acid or alkaline compounds from the sample, and to dissolve them in the water. This principle is utilized in the determination of neutralization number.

pH: Actual acidity or alkalinity, on the other hand, can be expressed in accordance with the pH scale, where zero represents maximum acidity, 14 maximum alkalinity, and 7 neutrality. The pH value of a solution can be determined electrolytically. When two electrodes of different materials are immersed in the solution, a small electric potential (voltage) is generated between them, and the magnitude and polarity of this potential can be related directly to pH value.

Potentiometric Method: The potentiometric method for determining neut number (ASTM D 664) is based on the electrolytic principle, pH, as indicated potentiometrically, is recorded against added reagent. If the initial pH reading of the specially prepared sample lies between 4 and 11 (approximately), the sample may contain weak acids, weak bases, or an equilibrium combination of the two. It may be titrated to one end point with base to yield a total acid number, and then may be titrated to another end point with acid to yield a total base number.

If, on the other hand, the initial pH reading lies below 4 (approximately), the sample may be

titrated with base up to this point to yield a strong acid number. It may also be titrated up to 11 (approximately) to yield a total acid number. Similarly, a sample whose initial pH reading lies above 11 (approximately) can be titrated with acid down to this value to yield a strong base number, and it can be titrated down to 4 (approximately) to yield a total base number.

End Points: Titration end points are not at fixed pH readings but at inflections that occur in the curve: reagent versus pH. Whether or not an end point represents a strictly neutral condition is of little significance. With test procedure carefully standardized, the results obtained in reaching an end point can be compared on an equal basis with other results obtained in the same way. A result reported simply as "neut number," moreover, may be assumed to be a total acid number. Although it is not provided for by ASTM procedure, the Initial pH reading may also be reported.

Colorimetric Method: Under the colorimetric method for determining neut number (ASTM D 974), end point is identified by the change of a color indicator. This indicator exhibits one color above a specified pH value, another below. By this means, a total acid or strong base number can be determined with a p-naph-tholbenzene indicator, while a strong acid number can be determined with a methyl orange indicator. Obviously, however, this method is not suitable for the investigation of dark-colored liquids.

Reporting the Results: Whatever the method, all acid numbers are expressed in milligrams of potassium hydroxide (KOH), a base, required to "neutralize" a gram of sample. For reasons of uniformity, base numbers, which are obtained by titrating with hydrochloric acid (HCl), are expressed in the same units, the HCl being converted to the number of KOH units that it would neutralize.

Significance of Test Results: Because acidity is associated with corrosiveness, there has been a tendency to attribute undesirable

properties to an oil that exhibits a high acid number or a low pH reading. This attitude is fostered by the fact that deterioration of an oil in service oxidation, is ordinarily accompanied by an increase in acid test results. While this attitude is not in actual disagreement with fact, its oversimplification may be conducive to harmful misconceptions.

In the first place, petroleum oil is not an aqueous solution, and conventional interpretations of acidity and alkalinity do not apply. In the second place, the test results, while involving certain acid or alkaline implications, do not distinguish between those that are undesirable and those that are not. The ASTM Standards themselves include the statement that the test "method is not intended to measure an absolute acidic or basic property that can be used to predict performance of an oil under service conditions. No general relationship between bearing corrosion and acid or base number is known."

This is not to say, however, that neut number or pH reading are without significance. They are applied widely and effectively to turbine oils, insulating oils, and many other oils in critical service. With new oils, neutralization test results provide a useful check on consistency of product quality. With used oils, they may serve as a guide to mechanical condition, change in operating conditions, or product deterioration. A rise in acid number and/or a drop in base number or pH reading are generally indicative of increasing oxidation. They may also be related to depletion of an additive, many of which are alkaline.

It is impossible, however, to generalize about the limits to which the neutralization values of an oil in service may safely be allowed to go. Each combination of oil, machine, and type of service follows a pattern of its own. Only through experience with a particular set of conditions can it be determined at what neutralization value an oil is no longer suitable for service.

OXIDATION STABILITY-OIL ASTM D 943

Oxidation is a form of deterioration to which all oils in service are exposed. It is a chemical reaction that occurs between portions of the oil and whatever oxygen may be present, usually the oxygen in the atmosphere. The oxidation of lubricating oils is accelerated by high temperatures, catalysts (such as copper), and the presence of water, acids, or solid contaminants. The rate of oxidation increases with time.

Oxidation tends to raise the viscosity of an oil. The products of oxidation are acid materials that lead to depositing of soft sludges or hard, varnish-like coatings. Paraffinic oils characteristically have greater oxidation resistance than naphthenic oils, although naphthenic oils are less likely to leave hard deposits. Whatever the net effect of oxidation, it is undesirable in any oil that lubricates on a long-term basis. Much has been done to improve oxidation resistance by the use of selected base stocks, special refining methods, and oxidation inhibitors. As might be expected, moreover, a great deal of study has been devoted to the means by which oxidation resistance of an oil may be evaluated.

A number of oxidation tests are in use. Some may be better related to a particular type of lubrication service than others. All are intended to simulate service conditions on an accelerated basis. At an elevated temperature, an oil sample is exposed to oxygen or air, and sometimes to water or catalysts, usually iron and/or copper. All of these factors make oxidation more rapid. Results are expressed in terms of the time required to produce a specified effect, the amount of sludge produced or oxygen consumed during a specified period.

One of the more common methods of examining steam turbine oils is the ASTM method D 943. This test is based on the time required for the development of a certain degree of oxidation under accelerated conditions, the greater the

time, the higher the oil's rating. Here, oxidation is determined by an increase in the oil's acidity, a property measured by its acid neutralization number.

It is sometimes preferred, however, to reverse this procedure and to measure the Increase in neutralization number incurred during a specified test run. In all cases, at least two samples of the oil under investigation are tested simultaneously in the same laboratory unit to reveal any concealed irregularity in procedure.

Procedure: A sample to be tested under the ASTM method is placed in a special oxidation cell, and a specified amount of distilled water is added to it. The cell is a large test tube fitted with a water-cooled condenser at the top to help prevent the escape of water vapor.

Oxygen enters through a glass tube around which a catalyst of copper wire and iron wire is coiled. The coil is submerged in the distilled water. Flow of oxygen through the cell is measured by a flowmeter.

The cell is immersed in a 203° F bath and supplied with oxygen introduced to the bottom of the tube at 3 liters per hour. Unless other provisions are made, the test is concluded when the acid number reaches 2.0

Reporting the Results: The oxidation life of the oil is generally reported as the number of hours required to reach the limiting acid number of 2.0. It may also be reported as the acid number, or rise in acid number, obtained after a test of specified duration. In many laboratories, moreover, increasing attention is being given to certain qualitative observations. Color and odor of the sample at prescribed stages of the test, also the presence of any rust or sludge, condition of the catalyst, etc., provide additional data sometimes considered in specifications and in product evaluation.

Significance of Results: Oxidation stability is an important factor in the prediction of an oil's performance. Without adequate oxidation stability, the service life of an oil may be extremely limited. Unless the oil is constantly replaced, there is a serious possibility of damage to lubricated parts. Acids formed by oxidation may be corrosive to metals with which the oil comes in contact. Sludges may become deposited on sliding surfaces, causing them to stick or wear, or they may plug oil screens or oil passages.

Oxidation stability is a prime requisite of oils serving in closed lubrication systems, where the oil is recirculated for extended periods. The higher the operating temperature, the greater the need for oxidation stability, especially if water, catalytic metals, or dirt are present. Resistance to oxidation is of special importance in a steam-turbine oil because of the serious consequences of turbine bearing failure. Gear oils, electric transformer oils, hydraulic fluids, heat-transfer oils, and many crankcase oils also require a high degree of oxidation stability.

Obviously, the ability to predict oxidation life by a test, and to do it with reasonable accuracy is highly desirable. There are certain factors, however, that make reliable test results difficult

to obtain. In the first place, the tests themselves are very time-consuming: a method such as ASTM D 943 may require the better part of a year to complete. Prolonged though the test may be, moreover, its duration usually represents but a small fraction of the service life of the oil under investigation. A steam turbine oil, for example, may well last for a decade or more without serious deterioration. It is impossible to reproduce service conditions of this sort in the laboratory with a test even of several hundred hours duration. And, in addition to the time factor, there are many other operational variables that cannot be duplicated under test conditions. Results can be distorted also by presence of certain additives in the oil.

For these reasons, the correlation between oxidation test results and field experience leaves much to be desired. Test results are subject only to broad Interpretations. It would be difficult to show, for example, that an oil with a 3000-hour ASTM test life gives better service than an oil with a 2500-hour test life. In evaluating the oxidation stability of an oil, primary consideration should be given to the record that it has established over the years in the type of service for which it is to be used.

POUR POINT ASTM D 97

It is often necessary to know how cold a particular petroleum oil can become before it loses its fluid characteristics. This information may be of considerable importance, for wide variations exist in this respect between different oils, even between oils of comparable viscosity.

If a lubricating oil is chilled sufficiently, it eventually reaches a temperature at which it will no longer flow under the influence of gravity. This condition may be brought about either by the

thickening of the oil that always accompanies a reduction in temperature, or by the crystallization of waxy materials that are contained in the oil and that restrain the flow of the fluid portions. For many applications, an oil that does not flow of its own accord at low temperatures will not provide satisfactory lubrication. The extent to which an oil can be safely chilled is indicated by its pour point, the lowest temperature at which the undisturbed oil can be poured from a container.

The behavior of an oil at low temperature depends upon the type of crude from which it is refined, the method of refining, and the presence of additives. Paraffinic base stocks contain waxy components that remain completely in solution at ordinary temperatures. When the temperature drops, however, these waxy components start to crystallize, and they become fully crystallized at a temperature slightly below the pour point. At this temperature, the undisturbed oil will not generally flow under the influence of gravity.

Crystallization of the waxy components does not mean that the oil is actually solidified; flow is prevented by the crystalline structure. If this structure is ruptured by agitation, the oil will proceed to flow, even though its temperature remains somewhat below the pour point.

An oil that is predominantly naphthenic, on the other hand, reacts in a somewhat different manner. In addition to having a comparatively low wax content, a naphthenic oil thickens more than a paraffinic oil of comparable viscosity does when it is cooled. For these reasons, its pour point may be determined by the actual congealing of the entire body of oil instead of by the formation of waxy crystals. In such a case, agitation has little effect upon fluidity, unless it raises the temperature.

The pour point of a paraffinic oil may be lowered substantially by a refining process that removes the waxy components. For many lubricating oils, however, these components impart advantages in viscosity index and oxidation stability. Good performance generally establishes a limit beyond which the removal of these waxy components is inadvisable. It is possible, nevertheless, to lower the pour point of a paraffinic oil by the introduction of a pour depressant. Such an additive appears to stunt the growth of the individual crystals so that they offer less restriction to the fluid portions of the oil. It is hardly necessary to point out, however,

that a pour depressant, as such, can have little, if any, effect upon a naphthenic oil.

Cloud point is the temperature, somewhat above the pour point, at which wax crystal formation gives the oil a cloudy appearance. Not all oils exhibit a cloud point and, although this property is related to pour point, it has little significance for lubricating oils. It is significant, however, for distillate fuels, and it is measured by ASTM D 2500.

Apparatus: The oil sample is contained in a jacketed glass test jar. The mouth of the jar is sealed with a cork through which a thermometer is introduced to indicate the temperature of the sample. This temperature is controlled by hot and cold baths in which the jacketed glass test jar may be partially immersed.

Procedure: The pour point of an oil may be distorted by its previous temperature history as well as by agitation. To assure reproducible results, elaborate sample pretreatment is required and specified heating and cooling procedures must be followed. Pretreatment consists of heating and cooling to prescribed temperatures, which are dependent on the expected pour point and type of oil being tested.

The heated oil is cooled in increments of 5° F. At each step, the test jar is removed from the bath and tilted for not over 3 seconds. This procedure is repeated until the sample ceases to show movement when tilted.

Reporting the results: The pour point is reported as the temperature 5° F above that at which the oil remained in position when the test jar was tilted. (For example: If the oil being tested shows movement at 10° F, but not at 5° F, the pour point is reported as 10° F.)

Significance: The pour point of an oil is related to its ability to start lubricating when a cold machine is put in operation. Agitation by the

pump will rupture any crystalline structure that may have formed, if the oil is not actually congealed, thereby restoring fluidity. But oil is usually supplied to the pump by gravity, and it can not be expected to reach the pump under these conditions, if the temperature is below the pour point. Passenger car engines and many machines that are stopped and started under low-temperature conditions require an oil that will flow readily when cold.

What is true of circulating lubrication systems, moreover, is equally true of gravity-feed oilers and hydraulic systems. A low-pour-point oil helps to provide full lubrication when the equipment is started and is easier to handle in cold weather. Low pour Point is especially desirable in a transformer oil, which must circulate under all temperature conditions. The control of large

aircraft is dependent upon hydraulic oils that must remain fluid after being exposed to extreme temperature drops. For these and similar applications, pour point is a very important consideration.

If the temperature of an oil does not drop below its pour point, the oil can be expected to flow without difficulty. It sometimes happens, however, that oil is stored for long periods at temperatures below the pour point. In some cases, the waxy crystalline structure that may be formed under these circumstances will not melt and redissolve when the temperature of the oil is raised back to the pour point. To pour the oil under these conditions, it is necessary to put the waxy crystals back in solution by heating the oil well above its pour point.

RUST-PREVENTIVE CHARACTERISTICS ASTM D 665

This test method was originally designed to indicate the ability of steam turbine oils to prevent the rusting of ferrous parts should water become mixed with the oil. While still used for this purpose, its application is now often extended to serve as an indication of rust preventive properties of other types of oils, particularly those used in circulating systems. It is a dynamic test, designed to simulate most of the conditions of actual operation.

In the method, a standard steel specimen is immersed in a mixture of the test oil and water under standard conditions and with constant stirring. At the end of a specified period, the steel specimen is examined for rust. Depending on the appearance of the specimen, the oil is rated as passing or failing.

Apparatus and Materials: The apparatus required consists of a constant-temperature oil

bath with cover, a 400-ml beaker with cover, grinding and polishing equipment, a stirrer, and a thermometer.

Water used for the test may be either distilled water (Procedure A of D 665) or synthetic sea water (Procedure B), depending on the information required of the test. Synthetic sea water is prepared according to a formula given in the ASTM method. The specimen used in the test is a cylinder of 1015, 1020, or 1025 carbon steel approximately 2.7 inches long and 0.50 inches in diameter. The specimens can be used more than once; they are prepared for each test by a grinding and polishing operation. Specimens are discarded when the diameter is reduced to 0.375 inch.

Procedure: The steel specimen is first prepared by grinding and polishing to remove surface blemishes. The 400-ml beaker is then

filled with 300 ml of the oil to be tested and placed in the bath, which is set to maintain the sample at 140° F. The thermometer and stirrer are inserted through the beaker cover and into the test oil. The stirrer is started, and when the temperature of the sample reaches 140° F, the steel specimen is inserted through another opening in the beaker cover. Stirring continues for 30 minutes, until the specimen is thoroughly wetted by the oil. The thermometer is then removed, and 30 ml of water (either the sea water solution or distilled water) is added through the thermometer opening. Stirring is continued until the test is terminated.

Observations of rusting made at the end of 12 hours are usually indicative of whether the oil will pass or fail, although it is customary to run the test for 24 hours, or even longer. At the end of the test, the steel specimen is removed and observations of rusting are made. A rusted specimen, according to the test method, is one on which any rust spot or streak is visible in "normal" light (about 60 foot-candles).

Determination of "Pass" or Fail": In order to report an oil as passing or failing, the test must be conducted in duplicate. An oil is reported as passing if specimens from both tests are rust-free at the end of the test period. An oil is reported as failing if both specimens are rusted at the end of the test periods.

If one of the specimens from the duplicate test is rusted while the other is free of rust, the tests are repeated on two additional specimens. If either of these shows rust, the oil is reported as failing.

Degrees of Rusting: An indication of the degree of rusting occurring in this test is sometimes desired. For such cases, the following classification is recommended:

Light Rusting--Rusting confined to not more than six spots, each of which is 1 mm or less in diameter.

Moderate Rusting--Rusting in excess of the preceding, but confined to less than 5% of the surface of the specimen.

Severe Rusting--Rust covering more than 5% of the surface of the specimen.

Reporting Results: Results obtained with a given oil are reported as "Pass" or "Fail." Since the test may be conducted with either distilled water or with synthetic sea water, and for varying periods of time, reports of results should always specify these conditions. For example: "Rust Test, ASTM D 665. Procedure B. 24 Hours--Pass."

Significance: When the lubricating oil of a turbine or other system is contaminated with water, rusting can result. Particles of rust in the oil can act as catalysts that tend to increase the rate of oil oxidation. Rust particles are abrasive, and cause wear and scoring of critical parts. In addition, rust particles can add to other contaminants in a circulating system, increasing the tendency toward the clogging of low clearance members, such as servo-valves, and increasing the probability of filter plugging.

In many cases, the rusting characteristics of the system in service are better than is indicated by testing a sample of the used oil. Because the polar rust inhibitor "plates out" on the metal surfaces (which are therefore adequately protected). The sample of oil, being somewhat depleted of the inhibitor, will then allow greater rusting in the test than would occur in service.

The relative ability of an oil to prevent rusting can become a critical property in many applications. As noted, this test method was originally applied exclusively to steam turbine oils. However, the test is now frequently applied to other oils in different types of applications, whenever undesirable water contamination is a possibility.

TIMKEN EXTREME PRESSURE TESTS

ASTM D 2509-Lubricating Greases

ASTM D 2782-Lubricating Fluids

For machine parts that encounter high unit loadings, the lubricant must be capable of maintaining a film that prevents metal-to-metal contact under the extreme pressures involved. Otherwise, scoring of the surfaces and possible failure of the parts will result. Special extreme pressure (EP) lubricants are required for such applications.

The Timken EP test is one of a number of bench tests that have been designed to simulate service conditions of extreme pressure, and to evaluate EP lubricants accordingly. In the Timken test, as in other EP tests, a rotating member is brought to bear against a stationary member, with lubrication provided by the lubricant under test. The lubricant is evaluated on the basis of its ability to prevent scoring of the metal surfaces.

Apparatus and Procedure: The Timken EP Test set-up consists of a special machine with a rotating mandrel and a lever arm upon which graduated loads can be placed to vary the pressure that the mandrel exerts on the stationary member. In the test, the mandrel is fitted with a hardened steel ring (actually the outer ring or cup of a tapered roller bearing). A flat steel block, against which the ring is rotated in the test, is also provided, together with a sufficient quantity of the lubricant under investigation.

If oil is to be tested, provision is made to circulate the oil to the mating surfaces; if grease is to be tested, a grease gun or special grease cylinder is provided to feed the grease at a uniform rate to the surfaces. To begin the test, the ring and block are locked into position, and lubricant is fed to the point of contact of the ring and the block. A specified load is placed on the lever arm and the machine is run (usually at 800 rpm)

for 10 minutes, or until failure occurs.

At the end of the run, the test block is inspected for scoring. If the block is scored, the procedure is repeated with progressively lighter loads, using a new steel ring and test block each time. When the edges of the wear scar show no irregularities due to metal pick-up, the last weight used is reported as the Timken OK load, in pounds.

If no scoring occurs on the first run, progressively heavier loads are used until the block is scored. The maximum load that can be applied on the lever arm without scoring is reported as the Timken OK Load. The minimum load required to cause scoring is reported as the score load.

In addition to the OK and score loads, the actual pressure at the point of contact is sometimes reported. This requires the use of a Brinnell microscope, with which the area of the wear scar is determined. Using the OK load, the unit loading in psi on the area of contact can then be calculated.

Significance: Only very general conclusions can be drawn from the Timken EP or any other EP test. Results should be related to additional information about the lubricant, such as anti-wear properties, type of additive, corrosion characteristics, and so forth. Used in this way, Timken EP results can provide an experienced engineer with valuable information pertaining to the performance of one lubricant relative to others. In addition, the Timken EP test is often used in the quality control of lubricants whose performance characteristics have already been established.

VISCOSITY

ASTM D 88, D 445, Redwood, and Engler

Viscosity is probably the most significant physical property of a petroleum lubricating oil. It is the measure of the oil's flow characteristics. The thicker the oil, the higher its viscosity, and the greater its resistance to flow. The mechanics of establishing a proper lubricating film depend largely upon viscosity.

To evaluate the viscosity of an oil numerically, any of several standard tests may be applied. Though these tests differ to a greater or lesser extent in detail, they are essentially the same in principle. They all measure the time required for a specified quantity of oil at a specified temperature to flow by gravity through an orifice or constriction of specified dimensions. The thicker the oil, the longer the time required for its passage.

Close control of oil temperature is important. The viscosity of ally petroleum oil increases when the oil is cooled and diminishes when it is heated. For this same reason, the viscosity value of an oil must always be accompanied by the temperature at which the viscosity was determined. The viscosity value by itself is meaningless.

The two commonest methods of testing the viscosity of a lubricating oil are the Saybolt and the kinematic. Of these, the Saybolt (ASTM D 88) is the method more frequently encountered in conjunction with lubricating oils. However, the kinematic method (ASTM D 445) is generally considered to be more precise. There are also the Redwood and the Engler methods, which are widely used in Europe, but only to a limited extent in the United States. Each test method requires its own apparatus--viscosimeter (or viscometer).

Apparatus: The Saybolt Universal viscosimeter is used for oils of low and intermediate viscosity. It consists of a cylindrical container for the oil sample with a receiving flask under it to catch

and measure oil discharged from the container. At the bottom of the container is an orifice of specified dimensions through which the oil flows. Flow of oil is stopped and started with a cork.

The oil container is jacketed with a water bath to facilitate maintenance of a constant oil temperature. Temperatures are checked by two thermometers, one in the oil and one in the water bath. To adjust the temperature, an external source of heat is applied to the bath. Flow of oil into the receiver is timed with a stop watch or equivalent device.

For very viscous oils, the Saybolt Furoil viscosimeter is used. This apparatus differs from the Saybolt Universal viscosimeter only in that it has a larger orifice. For heavy oils, the larger orifice helps confine the testing time to a reasonable length.

The kinematic viscosimeter performs very much the same function as the Saybolt viscosimeter, but its construction is quite different. Kinematic viscosity is usually determined by the Ubbelohde instrument, a sort of glass U-tube in which certain necessary bulbs and constructions have been incorporated. Each tube is rated according to velocity at which water passes through it, and there are different classes of tubes for different ranges of oil viscosity.

The Redwood apparatus and the Engler apparatus are of the same general type as the Saybolt.

Procedures:

(a) Saybolt Method--With the oil at test temperature, usually 100° F or 210° F, the cork is removed from the oil container, allowing oil to flow into the receiving flask. The time required to fill the flask to the 60-cc graduation mark is observed.

(b) Kinematic Method--The Ubbelohde tube is filled with oil to a prescribed level, and the proper oil temperature is attained by immersion of the tube in an oil bath. When this temperature is reached, the oil in one side of the tube is raised by suction to a specified height. Suction is then removed, and the oil is allowed to flow back down through a narrow capillary. Observing the upper level of the oil, the tester clocks the time required for this level to pass between two calibrated marks on the glass.

(c) Redwood and Engler Methods--These methods are similar in general procedure to the Saybolt.

Reporting the Results: Saybolt viscosities are reported as the number of elapsed seconds indicated by the timer. For Saybolt Universal viscosities, the units are Saybolt Seconds Universal (SSU), and for Saybolt Furol viscosities, the units are Saybolt Seconds Furol (SSF). For a given oil, the Saybolt Universal value will run about 10 times as high as the Saybolt Furol value at the same temperature.

For kinematic viscosity, the formula is: kinematic viscosity in centistokes (cSt) = Ct where C is the calibration constant of the particular viscosimeter and t is the observed time of flow. The value computed by this formula is reported in centistokes, units of kinematic viscosity.

Redwood and Engler viscosities are also based on the time of flow and are reported as "Redwood seconds" or "Engler degrees," as the case may be. In all instances, the test temperature is reported along with the corresponding viscosity.

Significance of Results: Viscosity is often the first consideration in the selection of a lubricating oil. For most effective lubrication, viscosity must conform to the speed, load, and temperature conditions of the bearing or other lubricated

part. Higher speeds, lower pressures, or lower temperatures require an oil of a lower viscosity grade. An oil that is heavier than necessary introduces excessive fluid friction and creates unnecessary drag.

Lower speeds, higher pressures, or higher temperatures, on the other hand, require an oil of a higher viscosity grade. An oil that is too light lacks the film strength necessary to carry the load and to give adequate protection to the wearing surfaces. For these reasons, viscosity tests play a major role in determining the lubricating properties of an oil.

In addition to the direct and more obvious conclusions to be drawn from the viscosity rating of an oil, however, certain information of an indirect sort is also available. Since, to begin with, the viscosity of the lube oil cut is determined by its distillation temperature, it is apparent that viscosity and volatility are related properties. In a general way, the lighter the oil, the greater its volatility, the more susceptible it is to evaporation. Under high-temperature operating conditions, therefore, the volatility of an oil, as indicated by its viscosity, should be taken into consideration.

Though the significance of viscosity test results has been considered from the standpoint of new oils, these tests also have a place in the evaluation of used oils. Oils drained from crankcases, circulating systems, or gear boxes are often analyzed to determine their fitness for further service or to diagnose defects in machine performance.

An increase in viscosity during service may often indicate oxidation of the oil. Oxidation of the oil molecule increases its size, thereby thickening the oil. When oxidation has progressed to the point of causing a material rise in viscosity, appreciable deterioration has taken place.

VISCOSITY INDEX

ASTM D 567 and D 2270

Liquids have a tendency to thin out when heated and to thicken when cooled. However, this response of viscosity to temperature changes is more pronounced in some liquids than in others.

Often, as with petroleum liquids, changes in viscosity can have marked effects upon its suitability for certain applications. The property of resisting changes in viscosity due to changes in temperature can be expressed as the viscosity index (V.I.). The viscosity index is an empirical, unitless number. The higher the V.I. of an oil, the less its viscosity changes with changes in temperature.

The Concept of Viscosity Index: One of the things that led to the development of a viscosity index was the eady observation that, for oils of equal viscosities at a given temperature, a naphthenic oil thinned out more at higher temperatures than did a paraffinic oil. However, there existed no single parameter that could express this type of response to temperature changes.

The viscosity index system that was developed to do this was based upon comparison of the viscosity characteristics of an oil with those of so-called "standard" oils. A naphthenic oil in a series of grades with different viscosities at a given temperature, and whose viscosities changed a great deal with temperature, was arbitrarily assigned a V.I. of zero. A paraffinic series, whose viscosities changed less with temperature than most of the oils that were then available, was assigned a V.I. of 100. With accurate viscosity data on these two series of oils, the V.I. of any oil could be expressed as a percentage factor relating the viscosities at 100° F of the test oil, the zero-V.I. oil, and the 100-

V.I., oil, all of which had the same viscosity at 210° F. This is the basis for the formula,

$$V.I. = \frac{L - U}{L - H} \times 100$$

where L is the viscosity at 100° F of the zero-V.I. oil, H is the viscosity at 100° F of the 100 V.I. oil, and U is the viscosity at 100° F of the unknown (test) oil.

The ASTM Standards: This viscosity index system eventually became the ASTM standard D 567, which has been used for years in the petroleum industry.

ASTM D 567 is a satisfactory V.I. system for most petroleum products. However, for V.I.'s above about 125, mathematical inconsistencies arise which become more pronounced with higher V.I.'s. Because products with very high V.I.'s are becoming more common, a method (ASTM D 2270) that eliminates these inconsistencies has been developed.

Calculating Viscosity Index: The viscosity index of an oil can be calculated from tables or charts included in the ASTM methods. For V.I.'s below 100, ASTM D 2270 and ASTM D 567 are identical, and either method may be used. For V.I.'s above 100, ASTM D 2270 should be used. Since ASTM D 2270 is suitable for all V.I.'s, it is the method now preferred by Exxon. V.I.'s in future publications will be reported as ASTM D 2270 values.

The V.I. of an oil may also be determined with reasonable accuracy by means of special homographs or charts developed from ASTM tables.

Significance of Viscosity Index: Lubricating oils are subjected to wide ranges of temperatures in service. At high temperatures, the viscosity of an oil may drop to a point where the lubricating film is broken, resulting in metal-to-metal contact and severe wear. At the other extreme, the oil may become too viscous for proper circulation, or may set up such high viscous forces that proper operation of machinery is difficult. Consequently, many applications require an oil with a high viscosity index.

In an automobile, for example, the crankcase oil must not be so thick at low starting temperatures as to impose excessive drag on the engine and to make cranking difficult. During the warm-up period, the oil must flow freely to provide full lubrication to all engine parts. After the oil has reached operating temperature, it must not thin out to the point where consumption is high or where the lubricating film can no longer carry its load.

Similarly, fluid in an aircraft hydraulic system

may be exposed to temperatures of 100° F or more on the ground, and to temperatures well below zero at high altitudes. For proper operation under these varying conditions, the viscosity of the hydraulic fluid should remain relatively constant, which requires a high viscosity index.

As suggested by the relationship between naphthenic and paraffinic oils, the viscosity index of an oil can sometimes be taken as an indication of the type of base stock. A straight mineral oil with a high V.I., 80 or above, is probably paraffinic, while a V.I. below about 40 usually indicates a naphthenic base stock.

In general, however, this relationship between V.I. and type of base stock holds only for straight mineral oils. The refining techniques and the additives that are available today make it possible to produce naphthenic oils with many of the characteristics, including V.I., of paraffinic oils. V.I., then, should be considered an indication of hydrocarbon composition only in the light of additional information.

WATER WASHOUT ASTM D 1264

Lubricating greases are often used in applications that involve operations under wet conditions where water may enter the mechanism and mix with the grease. Therefore, the ability of a grease to resist washout becomes an important property in the maintenance of a satisfactory lubricating film, and tests for evaluating the effect of water on grease properties are of considerable interest.

Greases can be resistant to water in several ways. Some greases completely reject the admixture of water or may retain it only as occluded droplets with little change in structure. Unless these greases are adequately inhibited against rusting they may be unsuitable for lubri-

cation under wet conditions since the "free" water could contact the metal surface and cause rusting.

Yet other greases that absorb water may be satisfactory under wet conditions. These types of grease absorb relatively large amounts of water by forming emulsions of water in oil. This absorption has little effect on the grease structure and leaves no "free" water to wet and rust the metal. Therefore, the grease continues to supply the proper lubrication while also acting as a rust preventive.

Other water-absorbing greases form thin fluid emulsions so that the grease structure is de-

stroyed. These are useless for operation under wet conditions, and can be considered to have poor water resistance.

There are many effects that water has on grease, and no single test can cover them all. Many of the tests are useful tools; however, the results are subject to the personal judgment of the test operator and much skill is needed to interpret their meaning. ASTM Method D 1264, "Water Washout Characteristics of Lubricating Greases," is one method of evaluating this property.

Apparatus: The equipment necessary for this test are: (1) a 204 K Conrad-type 8-ball bearing equipped with front and rear shields having a specified clearance, (2) a reservoir, (3) a bearing housing mount, (4) a circulating pump, (5) a drive motor, (6) a constant heat source, and (7) a thermometer or thermocouple.

Test Procedure: The ball bearing and shields are first cleaned and weighed. Then the bearing is packed with 4 grams of the test grease and rotated at 600 rpm for 1 hour while a jet of water is sprayed at either 100° F or 175° F on the bearing housing. After this period, the bearings and shields are removed, dried, and weighed. The percentage weight of the grease lost is determined.

Report: The average of duplicate tests is reported as the percentage weight of grease washed out at the test temperature. The temperature at which the bearing assembly and

grease were dried is indicated. This is significant in some cases because some weight loss may be experienced because of oil evaporation in greases containing low-viscosity oils.

Precision Reproducibility: Results obtained by each of two laboratories are not considered suspect unless they differ by more than 20 percent washout at 100° F or 25 percent washout at 175° F.

Because of the poor precision of this test other procedures are under study by ASTM.

Significance: Test results are useful for predicting the probable behavior of a grease in a shielded (not positively sealed) bearing exposed to the washing action of water. They are a measure of the solubility of a grease in water and give limited information on the effect of water on the grease structure. They say nothing about the rust preventive properties of the grease.

The test is a laboratory procedure and should not be considered equivalent to a service evaluation. Results on greases tested by this method may differ from service results because of differences in housing or seal design. Therefore a grease that proves unsatisfactory according to this test, may be satisfactory under service conditions if the housing or seal design is suitable.